
Life Science Research Objectives and Representative Experiments for the Space Station

Edited by

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PREFACE

This document is one in a series of reports which address the scientific rationales and experiments for animal and plant life sciences which might be conducted aboard an Earth-orbiting space station. Just as the space station configuration is in the early design and definition phase, so too are the scientific investigations which will someday be conducted therein. No experiments have been selected or investigators chosen. The experiments described in this report are merely representative of the kinds of activities that might be conducted. This information has been collected to help ensure that space station designers and equipment specifiers are responsive to their users, the science community.

Most of the material for this report was generated at a workshop sponsored by the NASA-Ames Research Center, Life Science Division, Advanced Programs Office held at San Juan Bautista, California, in October 1985. The participants were asked to describe scientific rationales and science objectives, and to give brief representative experiment descriptions compatible with expected space station accommodations, capabilities, and performance envelopes. Experiment descriptions included hypothesis, subject types, approach, equipment requirements, and space station support requirements. The experiments are divided into 14 disciplines.

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ACKNOWLEDGMENTS

This report is primarily the result of many hours of work by a dedicated group of 65 life science investigators inside and outside NASA. This group, including the NASA and contractor team which supported them in this effort, is listed in an appendix to the report, but the contributors are too numerous to thank individually. Their work is essential to advanced projects such as the space station and is greatly valued and appreciated.

Life science investigators who wish to conduct experiments in space have a special role to play in supporting NASA flight projects. They are frequently asked by NASA to make science-related projections which can be used for program planning and flight-research-facility development. These efforts are generally required years before any investigators will have the opportunity to write formal proposals and compete for funding by NASA to design and conduct an experiment. This report is a good example of this kind of contribution. In spite of the frequent requests made of them, usually with relatively short notice, and in spite of their already tight schedules, life science investigators make an extraordinary effort to respond to these requests. The group of contributors to this report was no exception.

Special thanks must go to those who designed and conducted the workshop on which this report is based. This group includes Adrian Mandel, the Ames Research Center Biological Research Project Science Coordinator; Richard Mains of Mains Associates, Science Consultant; and Yvonne Russell of Russmark, Inc., Technical Documentation Consultant who were instrumental in this effort. Richard Mains and Nina Saint of Mains Associates are primarily responsible for the production of this report, with strong support from Rodney Ballard, Research Scientist for the SETI Institute, and Kris Vogelsong and Joann Meredith of Bionetics Corporation. Kenneth Souza, Assistant Chief of the Ames Life Science Division, deserves many thanks for his continuing insistence that this effort was worthwhile and his enthusiasm and contributions during the workshop.

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CHAPTER 1: EXECUTIVE SUMMARY

A. INTRODUCTION

This report summarizes the results of a science workshop sponsored by the Biological Research Project of the Advanced Programs Office, Life Science Division, NASA Ames Research Center (ARC), which was held at San Juan Bautista, California, October 27-30, 1985. The principal purpose of the workshop was to define science objectives and representative experiments for conducting life science research on the Space Station Science Laboratory Module (SLM). The portion of the SLM which supports life science experiments has been named the Life Science Research Facility (LSRF). The representative experiments were used to determine general facilities and equipment necessary to outfit the LSRF for supporting research using animal and plant subjects and covering the major life science disciplines.

1. NASA Center Coordination

This report, prepared by the NASA ARC Biological Research Project (BRP), complements a similar report which defined science and hardware requirements for human subjects on the LSRF prepared by the Human Research Project at the Johnson Space Center (JSC) (JSC 20799). These two reports are being integrated into a common set of life science objectives for the space station. This effort is being coordinated by the Life Sciences Space Station Strategic Planning Committee, led by NASA Headquarters with members from both ARC and JSC. This integrated document, commonly known as the "Red Book," has now been published as NASA TM-89188.

2. Space Station Representative Experiments

Immediately prior to and during the workshop, a group of 65 life science investigators, representing 14 disciplines, wrote rationales, methods, hardware, and crew-time requirements for 171 preliminary, representative experiments based on the current space station operational guidelines. These experiments are described in this report.

B. WORKSHOP DESIGN, GOALS, AND PRODUCTS

At the ARC BRP workshop, current space station operational guidelines were presented to a broad group of NASA-experienced investigators to provide them with a foundation on which to develop experiments. They reviewed and edited the science objectives listed in the Red Book, generated others, and produced new, prioritized lists. Investigators were then asked to write representative experiments associated with the science objectives in their disciplines designed primarily for the Space Station Initial Operating Configuration (IOC) period, which was defined as lasting up to three years. Investigators used an ARC-provided format for this purpose.

One goal of the workshop was to incorporate experiment concepts from previous efforts of this type such as the McDonnell Douglas study, "Space Station Life Sciences Research Facility Technology Assessment and Technology Development Plan," NASA Contract NAS2-11539, December 1983. The McDonnell Douglas Study incorporated results from the earlier "Fabricant" and "Gomersall" space station life science studies. This compilation would provide a simple source of experiment descriptions which could become more detailed, be referenced in the Red Book, and provide requirements for space station design and definition studies for strategic planning. Another goal was to begin to integrate the efforts of plant and animal investigators with JSC human subject investigators. Because the LSRF is viewed as a generic facility, it

was essential to expand the number of disciplines addressed and investigators included, to a maximum, within the constraints of Project budget and schedule.

C. RESULTS, RECOMMENDATIONS, AND FUTURE WORK

1. Discipline Rationale

A brief summary of the rationale for the conduct of experiments on the space station is given below for each of 14 life science disciplines. A more detailed rationale is given for each discipline and associated experiments in the body of the report. A code is provided in parentheses after each discipline title; these codes are used in the data summaries provided in this section of the report. Also listed are the number of experiments generated within each discipline.

a. Biospherics (BS) (Global Biology) -- 7 Experiments

Remote sensing from the space station will provide life scientists with high-quality, continuous data to study cycling of materials and energy through the biosphere and Earth surface ecosystems in order to evaluate the impact of natural and human-caused factors.

b. Calcium Homeostasis (CH) -- 10 Experiments

Measurement of changes in bone dynamics and calcium metabolism during chronic microgravity will provide assessment of effects on the immature and mature vertebrate skeleton and the need for associated human countermeasures during spaceflight, prior to return to 1 g.

c. Cardiovascular System (CS) -- 8 Experiments

Understanding of the mechanisms of acute and chronic cardiovascular changes will allow an assessment of the significance for humans of return to 1 g, in-flight countermeasures, and the impact on vascular development in other vertebrates.

d. Controlled Ecological Life Support System (CELSS) (CL) -- 11 Experiments

Preliminary experiments are needed to verify the concept of bioregenerative human life support for long-duration manned spaceflight and planetary bases.

e. Endocrinology/Fluid and Electrolytes (E/FE) -- 1 Experiment

Changes in the neuroendocrine control of various physiological systems and the influence of plasma hormones on target organs and fluid/electrolyte balance changes need to be assessed during chronic microgravity.

f. Exobiology/Search for Extraterrestrial Intelligence (SETI) (ES/--) -- 13 Experiments (Subdivided into Exobiology, ES/EX -- 6 Experiments; and SETI, ES/SE -- 7 Experiments)

There is a requirement to study the origin, evolution, and distribution of life and life-related chemistry and to search for any possible living systems and civilizations throughout the universe.

g. Hematology (HE) -- 6 Experiments

The study of the effect of chronic microgravity on blood fluid and cells is required to develop effective countermeasures to mitigate the hematological abnormalities observed in spaceflight.

h. Immunology (IM) -- 6 Experiments

Immunosuppression is a potential consequence of long-term spaceflight in humans and the use of animal subjects will allow evaluation of the susceptibility to infection, in microgravity and following reentry.

i. Metabolic Regulation (MR/--) -- 15 Experiments

(Subdivided into Sleep/Performance, MR/SP -- 3 Experiments; Temperature Regulation/Metabolism, MR/TM -- 5 Experiments; Cell Biology, MR/CB -- 4 Experiments; and Circadian Rhythms, MR/CR -- 3 Experiments)

Animal subject adaptation to, and development within, the space station environment, will provide the first opportunity to study the magnitude, efficiency, regulation, and control of energy utilization in an environment free of Earth's gravity.

j. Muscle Structure and Function (MS/F) -- 6 Experiments

Animal subjects on the space station will provide the first opportunity to study mechanisms of muscle adaptation to chronic microgravity.

k. Neurosciences (NS) -- 31 Experiments

Space station animal experiments will allow detailed studies of the neural control of body movement in chronic microgravity, its effects on vestibular system anatomy and development, neuron physiology, reflexes, motion-sickness responses, and the readaptation to 1 g.

l. Plant Physiology (PL) -- 17 Experiments

Basic knowledge of plant growth and productivity on Earth and in space will be significantly advanced by long-term seed-to-seed experiments on the space station and will form the basis for future development of a CELSS for manned spaceflight.

m. Radiobiology (RA) -- 12 Experiments

Measurement of space station background radiation and assessment of its effects during long-term developmental animal and plant studies is critical because this factor may set the crew limit for total mission duration and influence all on-board living systems.

n. Reproduction and Development (R/D) -- 32 Experiments

The space station will provide the first opportunity to study the effects of long-duration spaceflight on animal reproduction and growth by allowing monitoring of basic developmental processes and determining their gravity and radiation thresholds.

2. Experiment Summary

The number of experiments produced by each discipline group is shown in the previous section. Differences in the number of experiments in each discipline were the result of several factors, including the total number of investigators available before and during the workshop, projections of anticipated spaceflight effects within the discipline, and discipline-related space station operational constraints. It is anticipated that additional investigator input will be required in the future to improve the experiment balance for some disciplines. However, the broad range of discipline types covered in the workshop and the large number of experiments generated should provide a representative sample of overall requirements for biological research on which to base LSRF design concepts.

3. Hardware Summary

A summary list of major hardware items required for 13 of the 14 disciplines is shown in table 1. The Biospherics and Exobiology/SETI disciplines require major hardware external to the LSRF. The hardware for Exobiology/SETI is not included in the hardware list. The hardware is listed in order according to the number of experiments which require each item. A brief description of hardware function is provided as a guide. Assessment of the ability of each hardware item to qualify for spaceflight and meet space station operational requirements is a task which needs to be conducted in the near future. This assessment may result in changes of items on the list.

4. Crew Time Summary

Table 2 shows crew-time range estimates (hr/90 days) for conducting experiment procedures within each discipline except Exobiology/SETI, exclusive of time required for monitoring and maintaining specimens and servicing experiment-related common laboratory hardware. Experiments within disciplines were grouped into low (0 - 40 hr), medium (41 - 60 hr), and high (61 hr or more) ranges. It can be seen that some disciplines appear in all three categories and thus have a wide range of estimated crew times, while others appear in only one section. Estimated crew times for each experiment are listed at the end of each discipline in the main body of this report.

5. Experiment Site Options Summary

Investigators analyzed experiments for site-option preference with the following choices: 1) conduct on the crew-supported LSRF, 2) conduct as a payload attached to the LSRF or the space station, or 3) conduct on a free-flying platform unattached to the space station. In general, investigators who required vertebrates and plants as subjects chose the LSRF as a preferred site with some of these indicating attached payloads if appropriate crew support or highly automated life support was available. Investigators who preferred sites other than within the LSRF either required no live subjects or only plants and invertebrates as subjects.

Other reasons for preferring a site remote from the LSRF are discussed in more detail in appendix C and include requirements for very low gravity levels or placement in orbits higher than planned for the space station for improved planetary monitoring purposes. A summary of site options is shown in table 3. Five of the 14 disciplines have experiments which are candidates for remote-site location.

6. Times for Servicing and Housekeeping Tasks

Based on joint discussions by workshop attendees representing science and engineering, the hardware items listed in table 4 are likely candidates for a future detailed analysis of housekeeping and servicing tasks and an estimation of associated crew times. These tasks are strong candidates for automation and robotics applications and the significant estimated crew times required may be minimized by these technologies. Crew time required for conducting a 90-day space station life sciences mission should include the time estimated for the conduct of all experiment procedures plus the time estimated for housekeeping and servicing of laboratory hardware. It is currently estimated that the total average crew time per day available on the Space Station at IOC for these combined LSRF procedures will be no more than 10 person-hours and possibly as low as 4 person-hours.

TABLE 1.- NUMBER OF EXPERIMENTS (13 DISCIPLINES) REQUIRING HARDWARE

Item	Description	ID #	Totals of 158 experiments
Hand wash facility	Clean hands	1	146
Trash compactor	Trash disposal	2	146
Multi-purpose work bench	Laminar flow glove box	3	139
Cage cleaner	Wash & sterilize cages	4	109
Rodent food	Food, 24 rats (90 day)	5	69
Rodent module	24 rats or equiv. 0-g	6	69
Rodent water	Water, 24 rats (90 day)	7	69
Fixation kit	Tissue preservation	8	53
Variable-g centrifuge (13')	Vbl-g, Rhesus, life support	9	48
Guillotine	Decapitation of rodents	10	42
Surgery/dissection kit	Medical instruments	11	37
Experiment control computer	Data collect & control	12	35
Refrigerator (4° C)	Cold storage (30 liter)	13	33
Video camera, recorder, supplies	Portable camera, tapes	14	30
Mass measure, small	Weigh subjects	15	29
Freezer (-20° C)	Sample storage (30 liter)	16	28
Plant gas supplies	CO2 (90 day)	17	23
Plant habitat	400 liter chamber, 0-g	18	23
Plant nutrient supply	Water, nutrients (90 day)	19	23
Squirrel monkey food	Food, 4 sq monkeys (90 day)	20	22
Squirrel monkey module	4 squirrel monkeys (90 day)	21	22
Squirrel monkey water	Water, 4 sq monkeys (90 day)	22	22
Freezer (-70° C)	Sample storage (30 liter)	23	21
Biotelemetry system	Biotelemetry/receiving	24	19
Implanted biotelemetry	EMG, EEG, EOG, ECG, etc.	25	19
Rhesus monkey food	Food, 2 Rhesus (90 day)	26	19
Rhesus monkey habitat	2 Rhesus vivarium, 0-g	27	19
Rhesus monkey water	Water, 2 Rhesus (90 day)	28	19
Seed planting kit	Seed, trays, tools	29	19
Centrifuge, refrigerated	Sample centrifugation	30	16
Biomedical recorder	Data recorder	31	15
G control centrifuge (8')	1-g rats, with life support	32	14
Vestibular Research Facility	Var-G yaw, pitch, roll	33	14
Hematocrit centrifuge	Determine hematocrit	34	14
Development module	8 rat equiv vivarium, 0-g	35	14
Freezer, cryo (-196° C)	Snap freeze	36	14
Cassette data recorder	8 ch. digital recorder	37	13
Radioactive tracer kit	In vitro tagging	38	13
Fluid handling kit	Pipettor, tips	39	13
Veterinary kit	Animal medical supplies	40	13
Hematology analyzer	Blood components	41	13
Hematology kit	Blood collection supplies	42	12
Radiation dosimeter (passive)	Radiation detection	43	12
G control centrifuge (5')	1-g rats, no life support	44	12
Gamma counter	Isotope studies	45	10
Micro computer system	General purpose computer	46	10
Radiation dosimeter (active)	Background radiation	47	10

TABLE 1.- CONTINUED

Item	Description	ID #	Totals of 158 experiments
G control centrifuge (small)	Small plant/tissue centrifuge	48	10
Blood gas analyzer	pH, pO ₂ , pCO ₂ of blood	49	9
Microscope, dissecting	Tissue dissection	50	9
Mass spectrometer	Environ. gas analysis	51	8
Rhesus restraint	Acute restraint	52	8
Sonomicrometer	3 channel	53	8
Blood pressure & flow equipment	Signal cond electronics	54	7
Cardiac output equipment	Measure heart output	55	7
Insect food	Food (90 days)	56	7
Insect habitat module	1 liter insect vivarium	57	7
Insect water	Water (90 days)	58	7
Cell culture apparatus	Tissue culture	59	7
Centrifuge, laboratory	Sample centrifugation	60	7
Plant harvesting kit	Harvest tools	61	6
Microscope, compound	Cell, tissue morphol	62	6
Fluid infusion system	Fluid administration	63	6
CAT scanner	Organ imaging	64	5
Muscle biopsy instruments	Take tissue samples	65	5
G control centrifuge (10')	1-g, sq monkey, life support	66	5
Gas chromatograph	Gas mixture analysis	67	5
Nonradioactive tracer kit	In vitro tagging	68	5
Rodent restraint	Acute rodent holder	69	5
Clinostat	Plant gravitational control	70	5
Metabolic habitat	Metabolic balance	71	4
Amphibian food	Food, 20 frogs (90 day)	72	4
Amphibian module	20 frog equiv vivar, 0-g	73	4
Amphibian water	Water, 20 frogs (90 day)	74	4
Whole body grad. layer calorimeter	Energy balance	75	4
High resolution imaging spect.	Spectrometer	76	4
Incubator	Cell & tissue growth	77	4
Rodent metabolic module	2 rat chambers, 0-g	78	4
Organ bisector	TBD	79	4
Animal perfusion kit	Tissue fixation	80	3
Mass measure, micro	Weigh samples	81	3
Media	Microbial growth	82	3
Performance evaluation facility	Rhesus behavioral responses	83	3
Squirrel monkey acute restraint	Restrain squirrel monkey	84	3
Ocean color imager	OCI	85	3
BIOSTACK radiation detector	Biological detector	86	2
Homogenizer	Blender	87	2
Avian food	Food, (90 day)	88	2
Avian module	300 liters air vol, 0-g	89	2
Avian water	Water, (90 day)	90	2
Cell counter	Automatic cell counter	91	2
Freeze dryer	Freeze dry samples	92	2
Intravenous fluids	Emergency fluids	93	2
Motion sickness indicator system	Motion sickness detection	94	2

TABLE 1.- CONCLUDED

Item	Description	ID #	Totals of 158 experiments
Raster processor	Workstation (Biospherics)	95	2
Auto. data collection & loc. sys.	ADCLs (Biopspherics)	96	2
Autoclave	Instrument sterilization	97	2
Bone mineral analyzer	Bone density	98	2
Cell culture plate reader	Cell identification	99	2
Primate optokinetic test device	Measure eye movement	100	2
Aquatic module	100 liter aquarium, 0-g	101	1
Bone biopsy instruments	Live bone sampler	102	1
Crystal growth facility	In vitro kidney stone growth	103	1
Electrolyte analyzer	Composition of fluids	104	1
Experimental monkey diet	Experiment specific food	105	1
Fish food	Food, 50 fish (90 day)	106	1
Fish water	Water, replen (90 day)	107	1
Force transducer	Muscle tension	108	1
Glucose analyzer	Determine glucose content	109	1
Histology kit	Cell & tissue staining	110	1
Limb plethysmograph	Volume measurement	111	1
Liquid scintillation counter	Tritium counting	112	1
Micro ultra centrifuge	Micro ultra centrifuge	113	1
Microbial analysis kit	microbial analysis kit	114	1
Muscle electrostimulator	muscle electrostimulator	115	1
Oscilloscope	Display for analog data	116	1
pH/specific ion meter	Acid-base/ion concentration	117	1
SLR 35mm camera	Camera	118	1
Spectrophotometer	UV/visible/NIR	119	1
Video microscope adaptor	Link microscope w/ video	120	1
X-Ray equipment	Bone imaging	121	1
Vis. infra-red/thermal IR scanner	VIS-IR-TIR scanner	122	1
Large format camera	LFC	123	1
Multispectral scanner	MSS	124	1
Synthetic-aperture radar	SAR	125	1
Xenon gas exchange system	Gas exchange	126	1
Infrared gas analyzer for CO2	CO2 analyzer	127	1
Humidity sensor for H2O	Monitor humidity	128	1

TABLE 2.- DISCIPLINES WITH EXPERIMENT CREW TIME ESTIMATES IN THREE RANGES

Disciplines	Crew Time Estimates		
	Level (hours/90 days)		
	Low (0-40)	Medium (41-60)	High (61-up)
Biospherics	X	X	
Calcium Homeostasis	X	X	X
Cardiovascular System	X	X	X
Controlled Ecological Life Support System (CELSS)	X		
Endocrinology/Fluid and Electrolytes			X
Hematology	X	X	
Immunology	X		
Metabolic Regulation	X	X	
Muscle Structure and Function	X	X	
Neurosciences	X	X	X
Plant Physiology	X		
Radiobiology	X	X	
Reproduction and Development	X	X	X

TABLE 3.- SITE OPTIONS LISTED BY INVESTIGATORS

Disciplines	Number of Experiments Listed for Each Site			
	LSRF	Attached Payload	Free-Flyer	TOTAL
Biospherics	4		7	7
Calcium Homeostasis	10			10
Cardiovascular System	8			8
CELSS*	11			11
Endocrinology/Fluid and Electrolytes	1			1
Exobiology/SETI	2	11	11	13
Hematology	6			6
Immunology	6			6
Metabolic Regulation	15			15
Muscle Structure and Function	6	1	1	6
Neurosciences	31			31
Plant Physiology*	17			17
Radiobiology	10	2		12
Reproduction and Development	31	2	3	32
TOTALS	158	16	22	175
*minus experiments listed in both	4	0	0	4
CELSS and plant physiology	154	16	22	171
Note: Some investigators chose more than one site option per experiment.				

TABLE 4.- CANDIDATE HARDWARE FOR AUTOMATION AND ROBOTIC APPLICATIONS ANALYSIS

Item	Description	ID #	Totals of 158 experiments
Hand wash facility	Clean hands	1	146
Trash compactor	Trash disposal	2	146
Multi-purpose work bench	Laminar flow glove box	3	139
Cage cleaner	Wash & sterilize cages	4	109
Rodent food	Food, 24 rats (90 day)	5	69
Rodent module	24 rats or equiv. 0-g	6	69
Rodent water	Water, 24 rats (90 day)	7	69
Variable-g centrifuge (13')	Vbl-g, Rhesus, life support	9	48
Video camera, recorder, supplies	Portable camera, tapes	14	30
Mass measure, small	Weigh subjects	15	29
Plant gas supplies	CO2 (90 day)	17	23
Plant habitat	400-liter chamber, 0-g	18	23
Plant nutrient supply	Water 4 sq monkeys (90 day)	19	23
Squirrel monkey food	Food, 4 sq monkeys (90 day)	20	22
Squirrel monkey module	4 squirrel monkeys (90 day)	21	22
Squirrel monkey water	Water, 4 sq monkeys (90 day)	22	22
Biotelemetry system	Biotelemetry/receiving	24	19
Implanted biotelemetry	EMG, EEG, EOG, ECG, etc.	25	19
Rhesus monkey food	Food, 2 Rhesus (90 day)	26	19
Rhesus monkey habitat	2 Rhesus vivarium, 0-g	27	19
Rhesus monkey water	Water, 2 Rhesus (90 day)	28	19
G control centrifuge (8')	1-g rats, with life support	32	14

CHAPTER 2: INTRODUCTION

A. SPACE STATION LIFE SCIENCE PROGRAM REQUIREMENTS

1. Background

The design of a space station LSRF would ideally begin when the science requirements and the level of on-board advanced technology are specified. In reality, the advanced-technology level is not yet determined and the space station concept itself is still evolving. In spite of this, the technology required for the IOC must begin development soon. In addition, it is a program requirement that there be "growth" capability on the LSRF to accommodate more highly advanced technology for the post-IOC period. These facts make the design a major challenge.

The LSRF design must be highly flexible in order to accommodate experiments from all major life science disciplines, changing science requirements, and changes in research direction influenced by initial experiment results. Some life science experiments can be conducted as attached payloads and on free-flying platforms if they are autonomous and require minimal crew support. These external research capabilities require more detailed definition than was accomplished in this report.

In the absence of detailed experiment requirements for the LSRF, it is essential that high-quality "representative experiments" be available to provide general design guidelines. It is this requirement which was primarily addressed in the October 1985 NASA ARC LSRF Science Workshop. The experiments described in this report are therefore generalized experiment "types" and do not constitute either a total or scientifically reviewed list of experiments for the space station. The experiments described herein were developed by investigators to meet the above program requirements. Actual experiments developed for the space station will be formal proposals based on thorough reviews of the literature, will include detailed hypotheses and methodologies, and will undergo rigorous peer review.

Several studies and reports have been produced in the past to meet similar program goals. The major reports of this type have been 1) the 1979-81 NASA Ames "Gomersall Report" which focused on unmanned space platforms and was revised in 1982 to include manned laboratory facilities, 2) the 1982 NASA-sponsored "Fabricant Report" based on six space station science workshops, and 3) the 1983 McDonnell Douglas "Space Station Life Sciences Research Facility Technology Assessment and Technology Development Plan" which described 54 experiment concepts in a standard format with input primarily from the first two reports.

2. ARC and JSC Experiment Integration

The space station offers opportunities to life science investigators never available before. The capability for conducting long-duration studies on humans, animals, and plants will provide data on the long-term adaptation to spaceflight and allow the conduct of high-quality, in-flight experiment controls. It is envisioned that there will be an increase in the integration and coordination of life science experiments sponsored by ARC and JSC which will provide new flexibility in choosing the optimum subject for the particular measurement desired. Future editions of the JSC and the ARC reports on space station life science objectives and requirements can be designed to further this goal.

B. WORKSHOP DESCRIPTION/REPORT

The 65 investigators who contributed experiments to the workshop represented 14 disciplines and are listed in appendix A. Of these, 27 investigators who attended the workshop and another 38 investigators provided experiments prior to and/or after the workshop. These investigators were affiliated with various universities, research institutes, medical centers, industries and NASA Centers.

An additional 10 workshop participants included NASA Headquarters personnel, JSC Payload Specialists, ARC Life Sciences management, Biological Research Project staff, and support contractors. This group presented a review of the space station operational guidelines, provided general workshop support, and reviewed investigators' recommendations for the LSRF definition and design process. A list of recommendations was obtained from the JSC payload specialists relating to future definition, development, and operation of LSRF equipment. This information is available within the project and will be used during future studies but is not included in this report.

The 171 experiments generated during the workshop were described on standard experiment description forms shown in chapter 3. Additional standardized forms listing candidate hardware items and experiment procedures (with estimated crew-time requirements) were provided to investigators to use as "worksheets" in defining these experiments so they would be based on standard nomenclature and times. These two latter forms are not included in this report, but, when available, input from the forms was used in preparation of the summary tables.

Because of limited investigator time, the experiment description task was simplified and standardized as much as possible. Two-thirds of the investigators were not able to complete the detailed hardware and procedure worksheets and thus the hardware and crew time data used for summary tables had to be obtained from their single-page experiment description forms. The hardware section on this form asked for a list of items other than common laboratory hardware (a list of examples was provided on the original). Thus the selection of obvious common hardware items for several experiments was conducted by ARC project staff based on the experiment subject type, sample analysis, and experiment controls listed for each.

Investigators provided drafts of the experiments to the project before, during, and after the workshop. These were edited and typed using the standard format and returned to each of the investigators for review and edit. Specific requests were made on each experiment to provide any missing data. Still, some of the experiments were returned with missing data, especially in the estimated crew-time and experiment-site sections. In cases where crew time could be easily estimated from a preceding experiment of the same type, the project filled in the estimate. The remainder of the experiments which had no estimate provided were listed as "to be determined" (TBD). Experiments which did not include a site preference were generally listed as requiring the LSRF if they used vertebrates as subjects or clearly required significant crew support. Others were listed as possible candidates for sites external to the LSRF or TBD.

Investigators were asked to review the McDonnell Douglas "54 Experiments" list from the Study described above during the workshop and either 1) rewrite the experiment in the format provided for this book or 2) delete the experiment and provide a justification for doing so. The disposition of each of the McDonnell Douglas experiments based on this method is summarized in appendix B to this report.

CHAPTER 3: DISCIPLINE RESULTS AND ANALYSIS

This chapter contains the summary results of the NASA ARC Biological Research Project Science Workshop. It is organized into 14 disciplines presented in alphabetical order. Each discipline section is labeled at the bottom of each page as a guide. Each discipline section is divided into the subsections described below.

DISCIPLINES:

- A. Biospherics (BS)
- B. Calcium Homeostasis (CH)
- C. Cardiovascular System (CS)
- D. Controlled Ecological Life Support System (CELSS) (CL)
- E. Endocrinology/Fluid and Electrolytes (EF/E)
- F. Exobiology/Search for Extraterrestrial Intelligence (SETI) (ES/--)
- G. Hematology (HE)
- H. Immunology (IM)
- I. Metabolic Regulation (MR/--)
- J. Muscle Structure and Function (MS/F)
- K. Neurosciences (NS)
- L. Plant Physiology (PL)
- M. Radiobiology (RA)
- N. Reproduction and Development (R/D)

SUBSECTIONS WITHIN EACH DISCIPLINE:

- Science Rationale
- Prioritized Science Objectives (with associated Experiments)
- Experiment Titles (with associated Science Objectives)
- Experiment Descriptions
- Experiment Hardware and Crew-Time Requirements

A. BIOSPHERICS

RATIONALE FOR BIOSPHERICS EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR BIOSPHERICS

BIOSPHERICS EXPERIMENT TITLES

BIOSPHERICS EXPERIMENT DESCRIPTIONS

BIOSPHERICS EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

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Biospherics

RATIONALE FOR BIOSPHERICS EXPERIMENTS ON SPACE STATION

The Biospherics program is directed toward studying life as a modulating energy force which governs the complex cycling of materials and energy throughout the biosphere of the Earth. In order to understand how existing life interacts with the environment on a global scale, an interdisciplinary approach is required that addresses the global system, or biosphere, in its entirety. The Biospherics program relies on remote sensing as a means to extrapolate ground-based, in situ parameters to a global scale. This includes studies of the influence of natural and human-caused changes in the processes that regulate the flow of chemical compounds through atmospheric, oceanic, and land processes.

Because different land-cover surfaces reflect different amounts of visible and infrared light in separate regions of the electromagnetic spectrum, the life scientist can utilize remotely sensed data to develop a "signature" for each surface material (trees, grasses, water, etc.). High-spectral-resolution data (in combination with high-ground-sampling frequency) will permit the detection of variations in life-dependent compounds within and between ecosystems. Ecosystem signatures may also permit estimates of large animal populations, and perhaps even the range and spread of selected insect species.

Biospheric research remote-sensing instruments may be attached to the Earth-pointing end of the space station, and/or located on polar or co-orbiting platforms.

PRIORITIZED SCIENCE OBJECTIVES FOR BIOSPHERICS

- BS-1** Understand the biochemical cycling of carbon, nitrogen, phosphorus, sulfur, and trace metals by using high-spectral-resolution imagers. (Red Book-1)
Experiments: BS-A, D
- BS-2** Determine primary biological oceanic productivity by use of Ocean Color Imager (OCI) or imaging spectrometer. (Red Book-None)
Experiments: BS-B
- BS-3** Understand and model environmental parameters which influence prevalence of vector-borne diseases using high-resolution visible and infrared or thermal data. (Red Book-None)
Experiments: BS-C
- BS-4** Define relationships between the environmental parameters and animal species of economic or scientific interest using NASA's synergistic imaging and tracking systems. (Red Book-None)
Experiments: BS-E, F, G
- BS-5** Determine effects of biomass combustion on the atmosphere and biota using remote-sensing techniques. (Red Book-None)
Experiments: BS-D

BIOSPHERICS EXPERIMENT TITLES

Code	Title	Objective
BS-A	Biochemical Contents of Plant Canopies	BS-1
BS-B	Primary Productivity in Equatorial Oceans	BS-2
BS-C	Predictive Modeling of Disease Transmission	BS-3
BS-D	Characterization of the Effects of Wildfires on the Atmosphere and Biota	BS-1, BS-5
BS-E	Evaluate Multispectral Scanner Data for Estimating Waterfowl Populations and Habitats	BS-4
BS-F	Determine Environment/Animal Relationships of Species Which Are Economically/ Scientifically Important	BS-4
BS-G	Define Environment/Animal Relationships in Migratory Species	BS-4

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Biospherics BS-A.
 - B. Science Objectives: BS-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Biochemical Contents of Plant Canopies.
2. **PURPOSE/HYPOTHESIS:** To use the unique characteristics of the space station platform (equatorial orbit, frequent passes over a ground point, tendable instruments, pointability of sensors) in order to experimentally test sensors optimized for biospheric studies such as the biochemical contents of plant canopies.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Observation in the tropical region using passive instruments is made difficult by local convective cloud buildup and the frequent overpass will help overcome this. Also, a new sensor to extract biochemical information needs to be evaluated by coordinating observations with ground study and being able to tune/adjust the instrument.
4. **APPROACH:**
 - A. Number/Type Specimens:
 - B. Measurements/Samples: High-spectral-resolution measurements (bandwidth (10-20 nm), range (400-2400 nm) sampled at 2-nm intervals in select regions) would be acquired over selected targets with simultaneous ground measurements. Frequent and timely observation could overcome logistic problems in tropics. Future Earth Observing System (EOS) designs can be optimized using tunable, pointable sensors.
 - C. Sample Analysis: On-board software preview.
 - D. Experiment Controls: Tunable, pointable sensors.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Adjustable High Resolution Imaging Spectrometer (HIRIS).
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 min/day = 45 hr.
 - C. Experiment Site: LSRF: poss Attached Payload: Platform: poss

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Biospherics BS-B.
 - B. Science Objectives: BS-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Primary Productivity in Equatorial Oceans.
2. **PURPOSE/HYPOTHESIS:** Determine primary productivity by use of ocean color as measured by an ocean color imager (OCI) or a moderate-resolution imaging spectrometer.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Remote sensing of equatorial oceans is not optimal from a polar-orbital platform because the high sun angles involved create too much sunglint; noon equatorial crossings also permit increased cloud development. The space station's equatorial orbit can be used to alleviate these problems.
4. **APPROACH:**
 - A. Number/Type Specimens: Acquire data at ~09:00 local solar time on each orbit over tropical oceans. One-km resolution preferred to exclude small clouds.
 - B. Measurements/Samples:
In-flight: Ocean color @ 443 nm, 490 nm, 520 nm, 565 nm, 620 nm, 665 nm, 765 nm, 865 nm, and 1060 nm, and 11.6 μm
 - C. Sample Analysis:
Postflight: Calibrated radiances, atmospheric correction, pigment determination, and productivity modeling.
 - D. Experiment Controls:
In-flight: Solar reference.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): OCI or moderate resolution imaging spectrometer.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 min/day = 30 hr.
 - C. Experiment Site: LSRF: poss Attached Payload: Platform: poss

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Biospherics BS-C.
 - B. Science Objectives: BS-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Predictive Modeling of Disease Transmission.
2. **PURPOSE/HYPOTHESIS:** To employ NASA technology in the study and modeling of environmental parameters which influence the distribution and prevalence of vector-borne diseases for the purpose of assisting in the determination of type, timing, and location of control methods for malaria-endemic regions.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Malaria is a global health problem which is on the increase. The World Health Organization reported 6.5 million cases world-wide. 46% of the world's population lives in areas where malaria currently exists. (These are primarily tropical/equatorial regions.)
4. **APPROACH:**
 - A. Number/Type Specimens: High-resolution remote sensing data need to be acquired on a near-daily basis. Spatial resolution should be approximately 30 m.
 - B. Measurements/Samples:
In-flight: High spatial resolution should be acquired in the visible, infrared and thermal regions of the electromagnetic region.
 - C. Sample Analysis:
Postflight: Remote-sensing and ground data will be integrated in a geographic information system for use in developing predictive models of malaria transmission.
 - D. Experiment Controls:
In-flight: Solar reference.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): High Resolution Imaging Spectrometer (HIRIS) or similar high-resolution instrument.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 min/day = 30 hr.
 - C. Experiment Site: LSRF: poss Attached Payload: Platform: poss

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Biospherics BS-D.
 - B. Science Objectives: BS-1, BS-5.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Characterization of the Effects of Wildfires on the Atmosphere and Biota.
2. **PURPOSE/HYPOTHESIS:** The purpose of this research is to characterize wildfires using remote-sensing techniques to determine the effects of biomass combustion on the atmosphere and the biota. Specific objectives include using remote-sensing techniques to a) quantify the production of volatiles and understand their effect on atmospheric chemistry, b) determine/measure the effects of fires on land processes, and c) investigate fire events and effects on regional and global scales.
3. **PROGRAM RATIONALE/JUSTIFICATION:** NASA is developing a new research emphasis that is global in scale and concerned with the Earth as an integrated system. A crucial component of this system is biogeochemical cycling. Fire can influence biogeochemical cycling in many ways, from stimulating growth to destroying entire soil-plant-animal relationships. Remote sensing can play a significant role in the prediction and detection of fire events and in providing information to predict effects of fire events on nutrient movement within and between ecosystems.
4. **APPROACH:**
 - A. Number/Type Specimens: Research requires collection of data over wildland fires in various ecosystems throughout the globe.
 - B. Measurements/Samples: Measurements required include 1) spectral measurements in the 0.4-12- μ m range, 2) fire extent, 3) fuel source, 4) location, and 5) plume height and size.
 - C. Sample Analysis: Analysis to include in-flight data reduction, postflight regression, and correlation analysis.
 - D. Experiment Controls:
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Visual Infra-Red/Thermal (VIS-IR-TIR) scanner, raster-processing workstation.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 min/day = 45 hr.
 - C. Experiment Site: LSRF: poss Attached Payload: Platform: poss

(Once the technology is proven on a space station, a polar-orbiting platform could be added.)

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**

A. Discipline/Expt. Code: Biospherics BS-E.

B. Science Objectives: BS-4.

C. McDAC Expt. Ref. #/Title (orig. or modified): Evaluate Multispectral Scanner Data for Estimating Waterfowl Populations and Habitats.

2. **PURPOSE/HYPOTHESIS:** The purpose of this research is to evaluate multispectral scanner data for estimating concentrations of waterfowl in major habitats. Objectives include evaluation of the relationship between spectral signatures and waterfowl densities and species composition.

3. **PROGRAM RATIONALE/JUSTIFICATION:** Accurate measurement of waterfowl populations is an important requirement for effective management of these resources. Most assessments of waterfowl populations are based on ocular estimates. However, visibility and observer biases can cause serious error in these surveys. Remote-sensing techniques have the potential for improving the accuracy of the airborne waterfowl surveys by providing more efficient and documentable estimates.

4. **APPROACH:**

A. Number/Type Specimens: Data will be required over nesting areas and migratory routes.

B. Measurements/Samples:

In-flight: Measurements to include both photographic and spectral measurements of concentrated waterfowl populations. Spectral measurements will be made in the 0.4-12- μ m range.

C. Sample Analysis:

In-flight: Analysis to include data reduction and preliminary analysis of data quality.

Postflight: Analysis will include raster processing, correlation and regression analysis, and verification of findings.

D. Experiment Controls:

5. **SPACE STATION RESOURCE REQUIREMENTS:**

A. Special Equipment (other than common items): Multispectral scanner, large-format camera, and a raster-processing workstation.

B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 min/day = 30 hr.

C. Experiment Site: LSRF: Attached Payload: Platform: \checkmark

(Co-orbiting platform or polar-orbiting platform.)

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:
 - A. Discipline/Expt. Code: Biospherics BS-F.
 - B. Science Objectives: BS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Determine Environment/Animal Relationships of Species Which are Economically/Scientifically Important.
2. PURPOSE/HYPOTHESIS: Define the relationships between threatened-food-source-related species and the environment using NASA's space station remote-sensing and tracking technology.
3. PROGRAM RATIONALE/JUSTIFICATION: NASA's space station synoptic overviews and tracking technology can provide desired new information to management agencies and research scientists for limited resource utilization and conservation.
4. APPROACH:
 - A. Number/Type Specimens: 1) Dolphins (tuna), 2) sea turtles, 3) the great whales.
 - B. Measurements/Samples: Ocean color imager (OCI), image spectrometer, buoy, boat, and study species radio signals will be combined with ambient satellite weather data.
 - C. Sample Analysis: Data sampling automatically 12 times daily. Crew and data ground receival facility will monitor data twice daily.
 - D. Experiment Controls: Ship and aircraft ground stations will collect ground truth at appropriate locations.
5. SPACE STATION RESOURCE REQUIREMENTS:
 - A. Special Equipment (other than common items): OCI, High Resolution Imaging Spectrometer (HIRIS), and Automatic Data Collection and Location System (ADCLS).
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 min/day = 30 hr.
 - C. Experiment Site: LSRF: Attached Payload: Platform: √

(Sensor location: Space station co-orbiting or polar-orbiting platform.)

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Biospherics BS-G.
 - B. Science Objectives: BS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Define Environment/Animal Relationships in Migratory Species.
2. **PURPOSE/HYPOTHESIS:** The purpose of this research is to use NASA's synergistic technologies of space station co-orbiting and polar-orbiting platforms to define the unknowns of animal migrations and their relationships to the Earth's biosphere, magnetosphere, and the solar system.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The processes by which many free-roaming animals find their way over immense migratory distances is not clearly understood. NASA's technology with synoptic overviews, tracking beacons, and remotely sensed environments can provide data for models to explain this phenomenal behavior.
4. **APPROACH:**
 - A. Number/Type Specimens: 1) Caribou, 2) walrus and seals, 3) raptors and waterfowl.
 - B. Measurements/Samples: Photographic, multispectral, and infrared imagery along with high-frequency radio signals.
 - C. Sample Analysis: Imagery and tracking beacon data taken twice daily. Downlink receiving station will verify data received once per day.
 - D. Experiment Controls: Ice-flow stations, ground stations, and aircraft underflight will collect ground truth at strategic locations.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Ocean Color Imager (OCI), High Resolution Imaging Spectrometer (HIRIS), Synthetic-Aperature Radar (SAR), and Automated Data Collection and Location System (ADCLS).
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 min/day = 45 hr.
 - C. Experiment Site: LSRF: Attached Payload: Platform: √
(Sensor location: Space station polar-orbiting platform.)

BIOSPHERICS EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

A. Hardware Requirements

The experiments associated with Biospherics are hardware-intensive and usually require crew interface. Although the sensors could be designed as unpressurized, remotely mounted units attached to the space station or on free-flying platforms, the sensors will often need to be pointed, refocused, and data-validated and enhanced by crew observations. It has been the experience of both U.S. and U.S.S.R. efforts that short-term phenomena can routinely require pointability, filter changes, magnification changes, second acquisition of data, and visual plume verification. Such nonrepeatable events as fire storms, smoke-plume mapping, biomass removal in large fires, dust storms, floods, animal migrations, and volcanic activity could account for the full time allotted to the crew in each experiment discipline.

In addition to the sensing instruments listed in each experiment area are the significant data-handling requirements. The high data rate of the new generation of remote sensors will require a new approach in data handling. The use of Artificial Intelligence (AI) in the form of expert systems to compress and process data both on board and in the ground stations is necessary. The first steps to produce these systems are under way at NASA Ames Research Center in the Space Station Commercialization program. The end products are yet to be completely defined. The space station users, crews/scientists, and commercial interests need to be aware of the necessity to process data by AI before transmission to the ground station.

Exactly how the United States wishes to approach this arena of the space station is still being formulated between the different governmental agencies (i.e., NASA, NOAA, USDA, USGS). Therefore, this section can be regarded as a firm place holder with the details of hardware and procedural definition under way.

B. Crew-Time Requirements

Procedures and crew time required to conduct experiments for this discipline are unique for the reasons stated in section A above. These experiments will require crew support for installation, activation, pointing, recalibration, lens/filter changes, film changes, data retrieval and handling, data interpretation, and repeated data acquisitions. Crew support will be on a daily basis. Future analysis of these procedures must await clearer definitions of experiment hardware.

BIOSPHERICS EQUIPMENT USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE						
		BS A	BS B	BS C	BS D	BS E	BS F	BS G
Crew Time (hours/90 days)		45	30	30	45	30	30	45
Item	4	1		1			1	1
High Resolution Imaging Spectrometer	3		1				1	1
Ocean Color Imager	2				1	1		
Raster Processor (workstation)	2						1	1
Automatic data collection and loc. sys.	1				1			
VIS-IR-TIR scanner	1					1		
Large format camera	1					1		
Multispectral scanner	1							1
Synthetic-aperture radar								

B. CALCIUM HOMEOSTASIS

RATIONALE FOR CALCIUM HOMEOSTASIS EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR CALCIUM HOMEOSTASIS

CALCIUM HOMEOSTASIS EXPERIMENT TITLES

CALCIUM HOMEOSTASIS EXPERIMENT DESCRIPTIONS

**CALCIUM HOMEOSTASIS EXPERIMENT HARDWARE AND CREW-TIME
REQUIREMENTS**

Calcium Homeostasis

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RATIONALE FOR CALCIUM HOMEOSTASIS EXPERIMENTS ON SPACE STATION

Spaceflight data in this discipline have come primarily from Skylab astronauts, Soviet Salyut 6 cosmonauts, and from rats which were grown on the Soviet Cosmos series or Spacelab 3. Significant long-term changes in bone and calcium metabolism are suggested from these earlier studies. Countermeasures such as in-flight exercise for the long-duration studies with humans have likely minimized some of these changes. Animal studies have been of much shorter duration and the proposed long-duration flights on the space station will dramatically increase the opportunity for conducting significant studies.

Two major areas should be studied. First, mechanisms involved in skeletal dynamics in humans during or following flight should be investigated and appropriate countermeasures tested. Second, basic studies on the effect of microgravity on skeletal growth and development and the results of changes in calcium metabolism should be investigated. The most critical question is whether gravitational unloading directly affects bone cells, resulting in skeletal changes or indirectly affects them through fluid shifts and kidney changes.

Other questions to be answered include:

1. Does the skeleton develop normally in the absence of gravity? Animals are born with nearly twice the number of bones present in the adult skeleton and this bone fusion appears to be sensitive to gravitational loading. How would a space-reared specimen adapt to a 1-g environment?
2. If less bone mass is formed in space, can animals adapt to a 1-g environment after one or more generations in space?
3. If animals in space have less bone mass and therefore fewer mineral stores, are they more dependent on gut absorption for their mineral supply?
4. Do changes in the cell cytoskeleton, gap junctions and subcellular particles occur during spaceflight? Do these occur initially at the organ or the cellular level?

The skeletal system is essential for animals to move and work in a 1-g environment. Changes in this system can not only impact the ability to move and work on Earth, but also may impair other physiological systems which are dependent upon the bone mineral reservoir for normal functioning.

PRIORITIZED SCIENCE OBJECTIVES FOR CALCIUM HOMEOSTASIS

- CH-1 Differentiate the primary causal factors influencing bone changes in microgravity or reduced gravity from the homeostatic responses of the calcium system. (Red Book 1)
Experiments: CH-A, C, D, E, F, G, J
- CH-2 Determine the magnitude, rates, and sites of bone mineral change resulting from exposure to microgravity. (Red Book 2)
Experiments: CH-B, D, G, J
- CH-3 Determine the effect of microgravity on risk factors for the development of renal stones. (Red Book 3)
Experiments: CH-I
- CH-4 Quantify the effect of dietary factors (oxalate, phosphate, protein, etc.) on calcium absorption and secretion and renal stone risk. (Red Book 4)
Experiments: CH-I
- CH-5 Delineate the histomorphometric changes in trabecular and cortical bone across species. (Red Book 5)
Experiments: CH-G, J
- CH-6 Determine whether bone loss as a result of microgravity is reversed following flight. (Red Book 6)
Experiments: CH-D, G, J
- CH-7 Determine the effects of microgravity on crystal growth of stone-forming salts (i.e., calcium oxalate and uric acid) in vitro and in vivo. (Red Book 7)
Experiments: CH-I
- CH-8 Investigate crystallization of calcium compounds (phosphate, hydroxyapatite, and oxalate) in microgravity.
Experiments: CH-I
- CH-9 Determine the mechanism for the observed decrease in net calcium absorption during spaceflight (absorption vs. secretion). (Red Book 8)
Experiments: CH-F
- CH-10 Determine the effects of microgravity on local bone changes (e.g., mechanical stress and piezo-electric stimulus, prostaglandins, and blood flow). (Red Book 9)
Experiments: CH-E, F, G, J
- CH-11 Ascertain microgravity effects on the chemical composition of bone. (Red Book 10)
Experiments: CH-D, G
- CH-12 Investigate protocols for exercise, electrical stimulation, and other countermeasures which might reduce microgravity-induced bone and muscle loss. (Red Book 11)
Experiments: CH-F, G, J
- CH-13 Correlate bone loss during spaceflight and ground simulation studies with loss of muscle and electrolytes. (Red Book 12)
Experiments: CH-F

Calcium Homeostasis

- CH-14 Compare effects of microgravity with changes observed in ground-based model systems. (Red Book 13)
Experiments: CH-E
- CH-15 Determine whether there is a primary renal calcium leak induced by microgravity. (Red Book 15)
Experiments: CH-F, I
- CH-16 Determine the relationship between microgravity and renal production and clearance of calcium-regulating hormones. (Red Book 16)
Experiments: CH-E, F
- CH-17 Determine the effects of microgravity on bone cell metabolism in vitro. (Red Book 17)
Experiments: CH-H
- CH-18 Determine the level and duration of artificial gravity needed to protect the skeleton during long-duration missions and its relevance to the risk of stone formation. (Red Book 18)
Experiments: CH-D, G, H, I

CALCIUM HOMEOSTASIS EXPERIMENT TITLES

Code	Title	Objective
CH-A	Histopathogenesis of Bone Loss in Microgravity	CH-1
CH-B	Sex Differences as a Factor in Loss of Bone from Different Skeletal Sites	CH-2
CH-C	Calcium Absorption and Homeostasis in Microgravity	CH-1
CH-D	Effect of Microgravity on Skeletal Growth, Maturity, and Calcium Metabolism	CH-1, CH-2, CH-6, CH-11
CH-E	Bone Response to Pregnancy and Lactation in Microgravity	CH-1, CH-10, CH-14, CH-16, CH-18
CH-F	Altered Skeletal Response to Homeostasis in Microgravity	CH-1, CH-9, CH-10, CH-12, CH-13, CH-15, CH-16
CH-G	Relationship Between Bone Formation and Bone Resorption Defects in Microgravity	CH-1, CH-2, CH-5, CH-6, CH-10, CH-11, CH-12, CH-18
CH-H	Effect of Microgravity on Bone Cell Growth: Isolation of Bone Growth Factor	CH-17, CH-18
CH-I	Crystal Growth of Renal-Stone Forming Salts In Microgravity	CH-3, CH-4, CH-7, CH-8, CH-15, CH-18
CH-J	Effects of Oxygen on Bone Resorption in Microgravity	CH-1, CH-2, CH-5, CH-6, CH-10, CH-12

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline: Calcium Homeostasis CH-A.
 - B. Science Objectives: CH-1.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Histopathogenesis of Bone Loss in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To examine histopathogenesis of bone loss in microgravity.
Hypothesis: (a) massive bone loss is associated with uncontrolled activation of osteoclasts; (b) there is loss of crystallites in resorbing bone which facilitates enzymic degradation of the matrix and promotes rapid bone loss; and (c) remaining bone has a greater fraction of unmineralized collagen, which inhibits new bone formation.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Mature Rhesus monkeys (*Macaca nemestrina* and *M. mulatta*) are known to have remodeling systems similar to those of man. Evaluations of bone cell types and collagen composition are required to define the effect of absence of 1-g mechanical loading on the remodeling system and on structural changes in the skeleton.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 unrestrained, adult male Rhesus monkeys.
 - B. Measurements/Samples:
Preflight: Label bone with time markers, tetracycline derivative.
In-flight: Label bone with time markers; biopsy tibial tuberosity and fix tissue in neutral formalin for 2-3 days, then in ethanol.
Postflight: Biopsy tibial tuberosity.
 - C. Sample Analysis:
In-flight: Tissue to be fixed in neutral formalin for 2-3 days and then in ethanol.
Postflight: Analyze tissue.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 4 adult male Rhesus monkeys.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Large primate holding and research facility.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 10 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Calcium Homeostasis CH-B.
 - B. Science Objectives: CH-2.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Sex Differences as a Factor in Loss of Bone from Different Skeletal Sites.
2. **PURPOSE/HYPOTHESIS:** To investigate whether sex differences determine the rate of loss of mineral from different skeletal sites. Hypothesis: As long as normal ovarian function is maintained in females, there will be no differences between sexes in bone mineral alterations in radius-ulna, tibia, and lumbar vertebra in microgravity environments.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Lack of ovarian function in mature Rhesus monkeys is known to increase rate of vertebral bone loss in the animal as is observed with postmenopausal patients. Evaluation of bone mineral content during spaceflight in relation to indices of ovarian function is required to determine potential sex-related effects of spaceflight on the human skeleton.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 male, 4 female unrestrained, adult Rhesus monkeys. Tests to be performed monthly.
 - B. Measurements/Samples:
Preflight: 48-hr urine sample collected in metabolic balance study. Bone mineral content to be measured in anesthetized animals by photon absorptionometry.
In-flight: Same as preflight.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: Analysis of bone mineral content by photon absorptionometry.
Postflight: Bioassay of urine samples for pituitary gonadotropin activity.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 4 male, 4 female Rhesus monkeys.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board dual-photon bone mineral analyzer and large primate holding and research facility.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 125-150 hr (25 hr for urine collections; 100 hr for bone mineral analysis.)
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:
 - A. Discipline/Expt. Code: Calcium Homeostasis CH-C.
 - B. Science Objectives: CH-1.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Calcium Absorption and Homeostasis in Microgravity.
2. PURPOSE/HYPOTHESIS: To measure gastrointestinal calcium absorption and parameters of calcium homeostasis in microgravity. Hypothesis: (a) increased fecal calcium seen within 2 wk of exposure to microgravity in primates is due to diminished calcium absorption along with increased calcium secretion; (b) these changes are independent of vitamin D3 metabolite level; and (c) fecal calcium changes are associated with an initial reduction of plasma parathormone level which reflects the primarily osseous resorptive response to microgravity.
3. PROGRAM RATIONALE/JUSTIFICATION: Mature Rhesus monkeys (*Macaca nemestrina* and *M. mulatta*) are known to have calcium homeostatic processes similar to those of humans. Evaluation of urine and fecal calcium is required to determine whether homeostatic mechanisms are involved with initiation and maintenance of bone loss in microgravity.
4. APPROACH:
 - A. Number/Type Specimens: 4 unrestrained, adult male Rhesus monkeys.
 - B. Measurements/Samples:

Preflight: Fecal and urine samples collected in metabolic balance study. Administer Calcium-47 intravenously and simultaneously Calcium-45 by stomach tube to anesthetized animal. Quantitative collection of urine samples 0-24 hr and 24-48 hr after administration of isotope.

In-flight: Same tests as preflight to be performed twice during 90-day flight. Fecal and urine samples frozen for postflight analysis.

Postflight: Same as preflight.
 - C. Sample Analysis:

In-flight: Count samples. Freeze plasma samples for ground-based analyses for vitamin D3 metabolites, parathyroid hormone, phosphate, and calcium.

Postflight: Same as in-flight.
 - D. Experiment Controls:

In-flight: None.

Ground-based: 4 adult male Rhesus monkeys.
5. SPACE STATION RESOURCE REQUIREMENTS:
 - A. Special Equipment (other than common items): Beta and gamma counters and large primate holding and research facility.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Calcium Homeostasis CH-D.
 - B. Science Objectives: CH-1, CH-2, CH-6, CH-11, CH-18.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effect of Microgravity on Skeletal Growth, Maturity, and Calcium Metabolism.
2. **PURPOSE/HYPOTHESIS:** To determine bone changes which occur in rats during 1 yr in flight. Hypothesis: (a) rats, sent into space as weanlings, will show significantly less skeletal growth than their Earth-bound counterparts; (b) the size, shape, and number of bones in flight animals will be different from ground-raised animals; (c) responses to provocative stimuli will be different in flight animals; and (d) readaptation to 1g will be more difficult with advancing age.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Gravity plays a major role in determining the size and shape of the skeletal system and is thought to be responsible for fusing many bones during growth. Rats achieve skeletal maturity within 1 yr of life. This experiment will explore the importance of gravity on growth and development of the rat skeletal system from weanling to 1 yr of age.
4. **APPROACH:**
 - A. Number/Type Specimens: 40 rats, 17-21 days old (rats born in-flight would be preferable if available; both F1 and F2 generations could be used).
 - B. Measurements/Samples:
Preflight: X-ray of total skeleton, body mass (if born in-flight, these measurements would be made in-flight).
In-flight: Body mass, bone markers, response to calcium load/deprivation every 90 days only on rats to be euthanized at 1 yr. Draw blood for analysis, remove bones from 5 rats every 90 days, return 5 rats to 1g every 90 days; collect urine/feces pools weekly and preserve for analysis postflight.
Postflight: Similar to in-flight.
 - C. Sample Analysis:
In-flight: Separate serum from blood and freeze.
Postflight: Perform electron microscopy, histomorphometry, or biochemical analysis on bones. Analyze urine/feces.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls; see flight animals for details.
Ground-based: 20 rats, 17-21 days old.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Holding facility that will support rats from weanling through adulthood (0.08-0.6 kg), rat guillotine, surgical supplies, 1-g on-board centrifuge, X-ray machine (if animals born in-flight).
 - B. Estimated Total Inflight Crew Time (hr/90 day, based on 1-g environment): Assumes 1) automated urine and fecal collections, and 2) automated feeders and lixits. $708/\text{yr} + 4 = 177 \text{ hr/90 day}$ (includes in-flight 1-g controls).
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Calcium Homeostasis CH-E.
 - B. Science Objectives: CH-1, CH-10, CH-14, CH-16.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Bone Response to Pregnancy and Lactation in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Purpose: To determine whether the skeletal response to pregnancy/lactation is altered by microgravity. Hypothesis: The normal homeostatic responses of the skeleton and intestine during pregnancy/lactation will be blunted by microgravity because the bone cells will be less responsive.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Pregnancy/lactation is a well-characterized perturbation to calcium homeostasis which involves multiple endocrine systems. Microgravity can alter the response of this system in several ways, including both calcium endocrinology and pituitary function. The effect of microgravity on the interaction between calcium homeostasis and pituitary function is unknown.
4. **APPROACH:**
 - A. Number/Type Specimens: 50 breeding rats (bred in-flight except for first group). Each rat will be bred only once.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Breed 10 rats each at 0, 29, 59, 89, and 119 days of flight. Euthanize 5 rats each at 20, 50, 80, 110, and 140 days (at delivery) for pregnant rats. Euthanize 5 rats each at 41, 71, 91, 131, and 161 days (at weaning) for lactating rats. Tissue harvest after tracer and tetracycline injections, and serum analysis.
Postflight: Similar to in-flight.
 - C. Sample Analysis:
In-flight: Serum analysis.
Postflight: Quantitative histomorphometry of multiple bones, autoradiography of bone cells, analysis of serum for gonadotropins and calciotropic hormones.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls; see flight animals for details.
Ground-based controls: 50 breeding rats; see flight animals for details.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Rat mating cages, tissue harvest equipment, on-board 1-g centrifuge with breeding facilities.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): $205 \times 0.6 = 123$ hr/90 day.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Calcium Homeostasis CH-F.
 - B. Science Objectives: CH-1, CH-9, CH-10, CH-15, CH-16, CH-12, CH-13.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Altered Skeletal Response to Homeostasis in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Purpose: To determine whether the primary defect in the response of bone to spaceflight is at the level of the bone or kidney. Hypothesis: In the adult skeleton during weightlessness, there is a primary increase in bone resorption coupled with a decrease in bone formation. The resorption increase is transient whereas the formation decrease is permanent. The kidney responds homeostatically to these bone changes.
3. **PROGRAM RATIONALE/JUSTIFICATION:** In order to develop countermeasures to the bone loss which occurs in flight, the basic physiological responses must be understood. This can only partially be done in humans because some countermeasure (exercise) will always be done. The Rhesus monkey is a suitable model to study the human skeletal system and some homeostatic responses.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 unrestrained adult male Rhesus monkeys (*Macaca mulatta*, 8-10 kg), conditioned.
 - B. Measurements/Samples:

Preflight: Serum, urine, and feces (urine and feces quantitatively collected at various times for chemical and biochemical analysis, stable calcium isotope tracer studies, and provocative tests of calcium homeostasis).

In-flight: Diet manipulation; injection of compounds to perturb Ca homeostasis at 15, 30, 60, 90, and 180 days in-flight; quantitative urine/fecal collections at intervals in-flight up to 180 days; stable calcium tracer injections.

Postflight: Similar to pre/in-flight to follow readaptation. Animals are allowed to recover up to 1 yr postflight.
 - C. Sample Analysis:

In-flight: Blood gas analysis.

Postflight: Calcium tracers (Ca^{48} , Ca^{46} , Ca^{40}), parathyroid hormone, calcitonin, vitamin D, osteocalcin, calcium, magnesium, and phosphate.
 - D. Experiment Controls:

In-flight: None.

Ground-based controls: 4 Rhesus monkeys; see flight animals for details.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Large primate holding facility for unrestrained monkeys, squeeze cage or other restraint system, blood gas analyzer, and in-flight partial metabolic collection (quantitative urine/fecal collections).
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 97 hr.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Calcium Homeostasis CH-G.
 - B. Science Objectives: CH-1, CH-2, CH-5, CH-6, CH-10, CH-11, CH-12, CH-18.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Relationship Between Bone Formation and Bone Resorption Defects in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Purpose: to determine whether (and how) the normally-coupled processes of bone formation and bone resorption are uncoupled in microgravity. Hypothesis: the known defect in osteoblast function in flight may modify the bone-resorptive response in both the juvenile and adult skeletons.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Bone loss in the adult skeleton can be due to decreased formation or increased resorption or both. The known defect in osteoblast maturation or function may be accompanied by decreases in skeletal coupling factors. It is necessary to know this if appropriate countermeasures are to be developed for long-term flight; the first piece of information necessary is the relationship between formation and resorption in both modeling and remodeling skeletons.
4. **APPROACH:**
 - A. Number/Type Specimens: 40 rats, (10 each at 30, 60, 90, and 120 days of age), 4 adult Rhesus monkeys, and 4 juvenile Rhesus monkeys.
 - B. Measurements/Samples:
 - Preflight: Rats: tracer injections, animal sacrifice, specimen fixation, stable calcium isotope tracer studies.
 - In-flight: Rats: same as preflight. Monkeys: vertebral trabecular and radius/femur cortical mineral content using high-precision computed tomography scanner at 30, 60, 90, and 120 days to quantify net bone mass changes at various skeletal sites; stable calcium isotope tracer studies at 60 and 120 days to quantify whole-body resorption and formation.
 - Postflight: Rats: same as preflight. Monkeys: tetracycline labels and bone biopsy; follow monkeys for recovery up to 1 yr.
 - C. Sample Analysis:
 - In-flight: Performs electron microscopy, histomorphometry, or biochemical analysis on bone.
 - Postflight: Same as in-flight.
 - D. Experiment Controls:
 - In-flight: 1-g centrifuge controls (rats only); see flight animals for details.
 - Ground-based: 40 rats and 8 monkeys; see flight animals for details.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Large primate holding facility, anesthetic delivery, high-precision CT scanner, collections from large primate metabolic facility for multiple 2-wk periods during flight.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 155 hr (rat) + 107 hr (monkey) for 120 days (adjusted for 90 days: $155 \times .75 = 116.25$ hr for rat; $107 \times .75 = 80.25$ hr for monkey -- 98 hr average for 90 days).
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

NOTE: This experiment can be done in conjunction with experiment MS/F-F.
Calcium Homeostasis

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Calcium Homeostasis CH-H.
 - B. Science Objectives: CH-17, CH-18.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effect of Microgravity on Bone Cell Growth: Isolation of Bone Growth Factor.
2. **PURPOSE/HYPOTHESIS:** Purpose: To test for differences in bone cell growth, cytoskeleton, and protein synthesis at 0 g, 0.5 g, 1 g, and 2 g; once differences are seen, isolate protein growth factor by 2-D gel electrophoresis. Hypothesis: bone changes during spaceflight occur at the cellular level and can be detected in bone cell culture.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Bone loss is one of the most serious long-term effects of spaceflight. It is possible that the bone loss caused by microgravity is due to a change in metabolism at a cellular level.
4. **APPROACH:**
 - A. Number/Type Specimens: 1) rat sarcoma bone cells (could be started from frozen culture) and 2) primary chick bone culture.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Sample cultures for cell number, protein synthesis, and cytoskeletal changes. During first week, sample daily; after first week, every 2 days. Fix 5 samples in quadruplicate throughout a 4-wk period.
Postflight: Same as in-flight.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of in-flight samples.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls; see flight experiment for details.
Ground-based: 1-g controls; see flight experiment for details.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Cogoli's 0- and 1-g cell incubator and modified incubators for multiple sampling.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 25 hr (10 hr for the cell culture; 15 hr for the primary chick culture).
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Calcium Homeostasis CH-I.
 - B. Science Objectives: CH-3, CH-4, CH-7, CH-8, CH-15, CH-18.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Crystal Growth of Renal-Stone-Forming Salts in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Purpose: To investigate in vitro and in vivo the effect of microgravity on the formation of renal stones and to determine whether growth can be modified. Hypothesis: Increased renal calcium clearance, changes in local pH, and intestinal handling of phosphate/oxalate will increase the risk for formation of renal stones in flight.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Renal stone formation, if it occurs, could be a major medical emergency in flight. Though no astronaut has been known to form stones in flight, the effect of microgravity on the production of factors which enhance or inhibit stone formation is completely unknown.
4. **APPROACH:**
 - A. Number/Type Specimens: 30 rats, 8 monkeys.
 - B. Measurements/Samples:

Preflight: Serum and urine for analysis. CT imaging of renal tract of rats and monkeys to determine presence of stones in control animals and in animals with diet modification to induce stone formation.

In-flight: CT imaging or sacrifice of animals at 30, 60, and 90 days; crystal growth experiments in vitro with factors to modify crystal growth; serum and urine collection for in-flight analysis.

Postflight: Same as preflight.
 - C. Sample Analysis:

In-flight: Chemical analysis of serum/urine for stone-forming factors (pyrophosphate, oxalate, ionized calcium, pH, pCO₂, etc.)

Postflight: Same as in-flight.
 - D. Experiment Controls:

In-flight: None.

Ground-based: 30 rats, 8 monkeys; see flight experiment for details.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Blood gas analyzer in flight, CT imaging (pre/post, possibly in-flight), and in-flight crystal growth facility.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 128 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Calcium Homeostasis CH- J.
 - B. Science Objectives: CH-1, CH-2, CH-5, CH-6, CH-10, CH-12.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effects of Oxygen on Bone Resorption in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Purpose: To determine whether osteoclast proliferation is stimulated by increased atmospheric oxygen in the microgravity environment. Hypothesis: Increased atmospheric oxygen will convert yellow marrow to red marrow in trabecular bone, and net recruitment and development of osteoclasts from the red marrow will increase. This will cause increased bone resorption and bone loss in trabecular bone.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Extravehicular activity will be a large part of space station crew time. During this time, crew will breathe an increased percentage of oxygen, and this can lead to a stimulation of bone resorption and net bone loss. The magnitude and sites of bone loss must be determined.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 adult male, unrestrained Rhesus monkeys, 50 adult (500 grams) rats.
 - B. Measurements/Samples:

Preflight: Rhesus--high-precision computed tomography bone mineral analysis at multiple sites for animals to be kept at 100% oxygen in microgravity for 30, 60, 90, and 120 days. If in-flight instrument is developed, do in-flight measurements at these times.

In-flight: See preflight; Rats--sacrifice 10 animals (5 zero-g, 5 1-g in-flight controls) after 15, 30, 60, 90, and 120 days of 100% oxygen.

Postflight: See preflight.
 - C. Sample Analysis:

In-flight: None.

Postflight: Histomorphometry of rat bones (multiple sites), measurements of bone mineral content during 1-yr recovery postflight in monkeys.
 - D. Experiment Controls:

In-flight: 1-g controls.

Ground-based: 4 Rhesus monkeys, 50 rats; see flight experiment for details.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Large primate holding facility with gas exchange/controlled atmosphere capability, high-precision computed tomography bone mineral analyzer, housing for 500-gram rats with controlled atmosphere, on-board 1-g rat centrifuge with controlled atmosphere.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 31 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

CALCIUM HOMEOSTASIS HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE									
		CH A	CH B	CH C	CH D	CH E	CH F	CH G	CH H	CH I	CH J
Crew time (hr/90 day)		10	125	20	177	123	97	98	25	128	31
Item											
Blood gas analyzer	3						1			1	1
Bone biopsy instruments	1	1									
Bone mineral analyzer	2		1								1
Cage cleaner	9	1	1	1	1	1	1	1		1	1
CAT Scanner	3							1		1	1
Centrifuge, laboratory	1					1					
Centrifuge, refrigerated	7		1	1	1	1		1		1	1
Crystal growth facility	1									1	
Development module	2				1	1					
Electrolyte analyzer	1									1	
Experimental monkey diet	1						1				
Fixation kit	7	1			1	1		1	1	1	1
Freezer (-70° C)	8		1	1	1	1	1	1		1	1
G control centrifuge (8')	4				1	1		1			1
Gamma counter	1			1							
Guillotine	5				1	1		1		1	1
Hand wash facility	10	1	1	1	1	1	1	1	1	1	1
Hematocrit centrifuge	1						1				
Hematology kit	3		1	1				1			
Incubator	1								1		
Liquid scintillation counter	1			1							
Mass measure, micro	1						1				
Mass measure, small	1				1						
Multi-purpose work bench	10	1	1	1	1	1	1	1	1	1	1
Nonradioactive tracer kit	4				1	1	1	1			
pH/specific ion meter	1									1	
Radioactive tracer kit	5			1	1	1	1	1			
Refrigerator (4° C)	7	1		1			1	1	1	1	1
Rhesus monkey food	7	1	1	1			1	1		1	1
Rhesus monkey habitat	7	1	1	1			1	1		1	1
Rhesus monkey water	7	1	1	1			1	1		1	1
Rodent food	5				1	1		1		1	1
Rodent module	5				1	1		1		1	1
Rodent water	5				1	1		1		1	1
Sonomicrometer	2	1						1			
Surgery/dissection kit	1				1						
Trash compactor	10	1	1	1	1	1	1	1	1	1	1
Veterinary kit	7	1	1	1			1	1		1	1
X-ray equipment	1				1						

C. CARDIOVASCULAR SYSTEM

RATIONALE FOR CARDIOVASCULAR SYSTEM EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR CARDIOVASCULAR SYSTEM

CARDIOVASCULAR SYSTEM EXPERIMENT TITLES

CARDIOVASCULAR SYSTEM EXPERIMENT DESCRIPTIONS

CARDIOVASCULAR SYSTEM EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

RATIONALE FOR CARDIOVASCULAR SYSTEM EXPERIMENTS ON SPACE STATION

Spaceflight experiments have indicated that significant changes occur in the cardiovascular system of both human and subhuman primates in microgravity. The data indicate that blood volume shifts centrally and may result in altered cardiac dimensions and cardiac output, and in redistribution of blood flow to vital organs. These cardiovascular changes may involve reflex adrenergic receptor control mechanisms and biochemical and ultrastructural alterations in myocardial and vascular tissue. It will be important to determine the mechanisms for cardiovascular alterations in microgravity, especially during long-term exposures.

The space station can provide the environment to study some of the adaptive cardiovascular changes in response to microgravity that significantly affect the human ability to work in space. Since spaceflight produces both short-term and long-term cardiovascular changes, the space station will afford an important first opportunity to study the long-term cardiovascular effects. It will be important to study not only the physiological adaptations, but also the underlying mechanisms for these cardiovascular adaptations to spaceflight. To accomplish this the Rhesus monkey is an ideal candidate because it is phylogenetically close to humans and is large enough to allow implantation of biotelemetry for monitoring internal pressures, flows, and dimensions; blood sampling; and tissue biopsies which cannot be accomplished in humans.

The use of chronic restraint and externalized fluid-filled catheters is not recommended for nonhuman primates on the space station, based on the anticipated negative effects on subject health and welfare and the high crew-time requirement for maintenance of external catheters. Biotelemetry systems will be important for monitoring cardiovascular parameters in conscious, unrestrained, nonhuman primates on the space station. Advanced technology methods such as implanted "vascular ports" combined with subject behavioral training and temporary restraints may provide capabilities for periodic blood sampling without a requirement for external catheters or tranquilization.

PRIORITIZED SCIENCE OBJECTIVES FOR CARDIOVASCULAR SYSTEM

- CS-1 Measure cardiac output, cardiac compliance, and regional blood flows during prolonged spaceflight and microgravity in the Rhesus monkey. (Red Book 1)
Experiments: CS-A, F
- CS-2 Determine whether prolonged spaceflight and microgravity alter reflex or adrenergic control of cardiac function and regional blood flow in the Rhesus monkey. (Red Book 3)
Experiments: CS-B, C, D, E
- CS-3 Study the significance of cardiovascular and microvascular changes in rodents during chronic microgravity and evaluate problems associated with return to a 1-g environment. (Red Book 1, 2)
Experiments: CS-G
- CS-4 Conduct morphological and biochemical measurements on rodent myocardial and vascular tissues to determine the degree and reversibility of molecular and cellular changes associated with chronic microgravity. (Red Book 2)
Experiments: CS-H

CARDIOVASCULAR SYSTEM EXPERIMENT TITLES

Code	Title	Objective
CS-A	Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; I. Neuroendocrine Response with Determination of Regional Blood Flow	CS-1
CS-B	Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; II. Hemodynamic Responses to Volume Changes	CS-2
CS-C	Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; III. Central and Regional Hemodynamic Responses to Adrenergic Stimulation and Blockade	CS-2
CS-D	Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; IV. Cardiac and Coronary Response With and Without Chronotropic Stimulation	CS-2
CS-E	Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; V. Comprehensive Cardiac and Peripheral Vascular Assessment	CS-2
CS-F	Direct Measure of Cerebral Perfusion in Spaceflight	CS-1
CS-G	Rodent Microcirculatory Changes in Long-Term Microgravity	CS-3
CS-H	Myocardial Changes in Rodents During and After Spaceflight	CS-4

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Cardiovascular System CS-A.
 - B. Science Objectives: CS-1.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; I. Neuroendocrine Response with Determination of Regional Blood Flow.
2. **PURPOSE/HYPOTHESIS:** Prolonged spaceflight and microgravity increase cardiac dimensions and pressures, which, in turn, alter cardiac output, redistribution of blood flow to vital organs, and adrenergic control and reflex control of the cardiovascular system.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Fluid shifts are known to occur during spaceflight and microgravity. The consequent increase in cardiac dimensions and pressures will, in turn, alter cardiac output and distribution of blood flow to vital organs and will result in altered regulation of the cardiovascular system by neurohumoral reflexes of the adrenergic nervous system.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 unrestrained, adult Rhesus monkeys.
 - B. Measurements/Samples:
Preflight: Microsphere injections.
In-flight: Monitoring twice weekly on a 90-day flight. All 4 animals should be flown on a single flight if possible. Microsphere injections will be administered early, mid, and late in-flight. Up to 12 channels of analog data with telemetry. Blood samples collected for ground-based analysis.
Postflight: Microsphere injections.
 - C. Sample Analysis:
In-flight: Periodic downlink data analysis.
Postflight: Analysis of samples collected in-flight.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 4 adult Rhesus monkeys.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Large primate holding and research facility with temporary restraint system. Refrigerated centrifuge and freezer (-80°C) needed for blood samples for catecholamines, atrial natriuretic factor, plasma renin, vasopressin, and aldosterone. Pressure transducers and sonomicrometer and telemetry system. Isotope kit, injection and withdrawal pump. Data storage system for launch.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 8.4 hr.
 - C. Experiment site: LSRF: √ Attached Payload: Platform:

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:
 - A. Discipline/Expt. Code: Cardiovascular System CS-B.
 - B. Science Objectives: CS-2.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; II. Hemodynamic Responses to Volume Changes.
2. PURPOSE/HYPOTHESIS: Prolonged spaceflight and microgravity increase cardiac dimensions and pressures, which in turn alter cardiac output, redistribution of blood flow to vital organs, and adrenergic control and reflex control of the cardiovascular system.
3. PROGRAM RATIONALE/JUSTIFICATION: Fluid shifts are known to occur during spaceflight and microgravity. The consequent increase in cardiac dimensions and pressures will, in turn, alter cardiac output and distribution of blood flow to vital organs and will result in altered regulation of the cardiovascular system by neurohumoral reflexes of the adrenergic nervous system.
4. APPROACH:
 - A. Number/Type Specimens: 4 unrestrained, adult Rhesus monkeys.
 - B. Measurements/Samples:

Preflight: Measurements of cardiac output and renal, mesenteric, and iliac blood flows and measurements of aortic and right ventricular oxygen, hematocrit, hemoglobin, red blood cell mass and blood volume, and electrolytes during vena caval occlusion and bilateral carotid occlusion and volume expansion will be used to test reflex control of the circulation. Blood samples collected for ground-based analysis.

In-flight: Same as preflight.

Postflight: Same as preflight.
 - C. Sample Analysis:

In-flight: Periodic downlink data analysis.

Postflight: Analysis of samples collected in-flight.
 - D. Experiment Controls:

In-flight: None.

Ground-based: 4 adult Rhesus monkeys.
5. SPACE STATION RESOURCE REQUIREMENTS:
 - A. Special Equipment (other than common items): Large primate holding and research facility with temporary restraint system. Refrigerated centrifuge and freezer (-80°C) needed for blood samples for catecholamines, atrial natriuretic factor, plasma renin, vasopressin, and aldosterone. Pressure transducers and sonomicrometer and telemetry system. Isotope kit, injection and withdrawal pump. Data storage system for launch.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 16.8 hr.
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Cardiovascular System CS-C.
 - B. Science Objectives: CS-2.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; III. Central and Regional Hemodynamic Responses to Adrenergic Stimulation and Blockade.
2. **PURPOSE/HYPOTHESIS:** Prolonged spaceflight and microgravity increase cardiac dimensions and pressures, which in turn alter cardiac output, redistribution of blood flow to vital organs, and adrenergic control and reflex control of the cardiovascular system.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Fluid shifts are known to occur during spaceflight and microgravity. The consequent increase in cardiac dimensions and pressures will, in turn, alter cardiac output and distribution of blood flow to vital organs and will result in altered regulation of the cardiovascular system by neurohumoral reflexes of the adrenergic nervous system.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 unrestrained, adult Rhesus monkeys.
 - B. Measurements/Samples:

Preflight: Measurements of cardiac output and regional blood flows to renal, mesenteric, and iliac circulations during administration of alpha 1, alpha 2, beta 1, beta 2 adrenergic agonists and antagonists will test the integrity of the sympathetic system. Cardiac and vascular receptors will be studied upon return to normal gravity. Blood samples collected for ground-based analysis.

In-flight: Same as preflight.

Postflight: Same as preflight.
 - C. Sample Analysis:

In-flight: Periodic downlink data analysis.

Postflight: Analysis of samples collected in-flight for catecholamines, atrial natriuretic factor, plasma renin, vasopressin, and aldosterone.
 - D. Experiment Controls:

In-flight: None.

Ground-based: 4 adult Rhesus monkeys.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Large primate holding and research facility with temporary restraint system. Refrigerated centrifuge and freezer (-80°C) needed for blood samples. Pressure transducers and sonomicrometer and telemetry system. Isotope kit, injection and withdrawal pump. Data storage system for launch.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 16.8 hr.
 - C. Experiment site: LSRF: ✓ Attached Payload: Platform:

Cardiovascular System

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Cardiovascular System CS-D.
 - B. Science Objectives: CS-2.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; IV. Cardiac and Coronary Response With and Without Chronotropic Stimulation.
2. **PURPOSE/HYPOTHESIS:** Prolonged spaceflight and microgravity increase cardiac dimensions and pressures, which in turn alter cardiac output, redistribution of blood flow to vital organs, and adrenergic control and reflex control of the cardiovascular system.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Fluid shifts are known to occur during spaceflight and microgravity. The consequent increase in cardiac dimensions and pressures will, in turn, alter cardiac output and distribution of blood flow to vital organs and will result in altered regulation of the cardiovascular system by neurohumoral reflexes of the adrenergic nervous system.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 unrestrained, adult Rhesus monkeys.
 - B. Measurements/Samples:

Preflight: Measurements made of left ventricular diameter, wall thickness and atrial dimensions, and left ventricular pressure during experiments involving inferior vena caval occlusion, bilateral carotid occlusion, and volume expansion will test reflex control of the circulation and examine changes in diastolic compliance. The heart will be paced to test coronary vascular reserve. Blood samples collected for ground-based analysis.

In-flight: Same as preflight.

Postflight: Same as preflight.
 - C. Sample Analysis:

In-flight: Periodic downlink data analysis.

Postflight: Analysis of samples collected in-flight for catecholamines, atrial natriuretic factor, plasma renin, vasopressin, and aldosterone.
 - D. Experiment Controls:

In-flight: None.

Ground-based: 4 adult Rhesus monkeys.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Large primate holding and research facility with temporary restraint system. Refrigerated centrifuge and freezer (-80°C) needed for blood samples. Pressure transducers and sonomicrometer and telemetry system. Isotope kit, injection and withdrawal pump. Data storage system for launch.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 16.8 hr.
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

Cardiovascular System

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Cardiovascular System CS-E.
 - B. Science Objectives: CS-2.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effect of Spaceflight on Cardiovascular Control in Rhesus Monkeys; V. Comprehensive Cardiac and Peripheral Vascular Assessment.
2. **PURPOSE/HYPOTHESIS:** Prolonged spaceflight and microgravity increase cardiac dimensions and pressures, which in turn alter cardiac output, redistribution of blood flow to vital organs, and adrenergic control and reflex control of the cardiovascular system.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Fluid shifts are known to occur during spaceflight and microgravity. The consequent increase in cardiac dimensions and pressures will, in turn, alter cardiac output and distribution of blood flow to vital organs and will result in altered regulation of the cardiovascular system by neurohumoral reflexes of the adrenergic nervous system.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 unrestrained, adult Rhesus monkeys.
 - B. Measurements/Samples:

Preflight: Measurements made of left ventricular diameter, wall thickness and atrial dimensions, and left ventricular pressure during experiments administering alpha 1, alpha 2, beta 1, beta 2 adrenergic agonists and antagonists will be used to test reflex control of the sympathetic nervous system and its effects on diastolic compliance. Blood samples collected for ground-based analysis.

Inflight: Same as preflight.

Postflight: Same as preflight.
 - C. Sample Analysis:

In-flight: Periodic downlink data analysis.

Postflight: Analysis of samples collected in-flight for catecholamines, atrial natriuretic factor, plasma renin, vasopressin, and aldosterone.
 - D. Experiment Controls:

In-flight: None.

Ground-based: 4 adult Rhesus monkeys.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Large primate holding and research facility with temporary restraint system. Refrigerated centrifuge and freezer (-80°C) needed for blood samples. Pressure transducers and sonomicrometer and telemetry system. Isotope kit, injection and withdrawal pump. Data storage system for launch.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 16.8 hr.
 - C. Experiment site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Cardiovascular System CS-F.
 - B. Science Objectives: CS-1.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Direct Measurement of Cerebral Perfusion in Spaceflight.
2. **PURPOSE/HYPOTHESIS:** Purpose: Directly quantify changes in regional brain perfusion during flight. Hypothesis: Regional cerebral perfusion will change in flight because of fluid shifts.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Performance of tasks on the space station, especially during EVA, may depend in part on the capacity of the cardiovascular system to maintain adequate regional cerebral perfusion in humans or large primates.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 adult male Rhesus monkeys.
 - B. Measurements/Samples:
Preflight: Measurement of regional cerebral perfusion using xenon-enhanced computed tomography imaging.
In-flight: Same as preflight at 2, 5, 15, 30, 60, 90, and 120 days of flight.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: Arterial xenon concentration monitored during studies.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 4 adult male Rhesus monkeys.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): High-precision computed tomography scanner. Large primate holding facility. Xenon gas exchange system.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 hr.
 - C. Experiment site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Cardiovascular System CS-G.
 - B. Science Objectives: CS-3.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Rodent Microcirculatory Changes in Long-Term Microgravity.
2. **PURPOSE/HYPOTHESIS:** Changes in blood flow and distribution produce alterations in microvascular structure and function.
3. **PROGRAM RATIONALE/JUSTIFICATION:** One-g studies of rodents with hyperkinetic or hypokinetic circulation show changes in microvascular structure and function. Similar changes are likely to occur in microgravity. Characterization of these changes might provide a better understanding of (a) the cardiovascular problems encountered on return to a 1-g environment and (b) mammalian microvascular function.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 Sprague-Dawley adult male rats, 150-200 grams, instrumented with right atrial and aortic pressure catheters, an aortic electromagnetic flow probe, and a dorsal microcirculatory chamber.
 - B. Measurements/Samples:

Preflight: Measurements of heart rate, right atrial pressure, aortic pressure, still and video photomicroscopy of dorsal microcirculatory chamber, weight.

In-flight: Weekly measurements of heart rate, right atrial pressure, aortic pressure, still and video photomicroscopy of dorsal microcirculatory chamber, weight every 2 wk. Drug studies, including adrenergic agonists and antagonists to examine changes in reflex control and sensitivity.

Postflight: Same as preflight; check rate of readaptation.
 - C. Sample Analysis:

In-flight: Hematocrit early, mid, and late flight.

Postflight: Hematocrit.
 - D. Experiment Controls:

In-flight: None.

Ground-based: 12 adult male Sprague-Dawley rats, instrumented.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Videomicroscopy apparatus, co-observation tube for microscope, SLR 35-mm camera, rodent restraint, drug kit.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):

Study 6 rats/wk x 8 wk x 6 hr/session	= 48 hr
Rodent harvest @ 6 hr/4 rats	= 18 hr
Blood/hematocrit processing @ 2 hr/6 rats	= 12 hr

General rodent maintenance @ 0.5 hr/day	= 45 hr
Rodent weights every 2 wks @ 0.25 hr x 8wk x 12	= 12 hr

C. Experiment site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Cardiovascular System CS-H.
 - B. Science Objectives: CS-4.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Myocardial Changes in Rodents During and After Spaceflight.
2. **PURPOSE/HYPOTHESIS:** Animal experiments to date (simulated or flight) show changes in heart function. Morphological and biochemical tests will be carried out to measure the degree and reversibility of molecular and cellular changes associated with weightlessness.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Changes in cardiac muscle due either to increased gravity or to microgravity may be either transient or chronic. Recovery would be measured by (a) exposing the animal to gravity in flight (with an on-board centrifuge) and by (b) determining recovery times upon reentry.
4. **APPROACH:**
 - A. Number/Type Specimens: 42 young adult, male Sprague-Dawley rats. Hearts extracted from each experimental group. Four in-flight groups and three recovery groups. Six rats/group (minimum).
 - B. Measurements/Samples:

Preflight: None.

In-flight: Tissue collection, fixation for ultrastructural studies, freezing for biochemical studies.

Postflight: Sacrifice returned animals to obtain hearts for ultrastructural biochemical studies.
 - C. Sample Analysis:

In-flight: None.

Postflight: Analysis of samples collected in flight.
 - D. Experiment Controls:

In-flight: 1-g centrifuge controls.

Ground-based: Synchronous and vivarium.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Fixative for electron microscopy. Rapid removal of tissue required.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):

Daily maintenance	1 hr/day X 90 days	= 90 hr
Rodent harvest	6 rats/6 hr X 4/90 days	= 24 hr
Weighing rats	0.25 hr/rat/wk X 42 rats X 3 wk	= 106.5 hr
TOTAL		= 220.5 hr
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

CARDIOVASCULAR SYSTEM HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE							
		CS A	CS B	CS C	CS D	CS E	CS F	CS G	CS H
Crew time (hr/90 day)		8	17	17	17	17	30	78	24
Item									
Bio telemetry	6	1	1	1	1	1	1		
Biomedical recorder	6	1	1	1	1	1	1		
Blood gas analyzer	6	1	1	1	1	1	1		
Blood pressure & flow equip	7	1	1	1	1	1	1	1	
Cage cleaner	8	1	1	1	1	1	1	1	1
Cardiac output equipment	7	1	1	1	1	1	1	1	
Cassette data recorder	6	1	1	1	1	1	1		
CAT scanner	1						1		
Centrifuge, laboratory	1							1	
Centrifuge, refrigerated	6	1	1	1	1	1	1		
Experiment control computer	7	1	1	1	1	1	1	1	
Fixation kit	2							1	1
Fluid infusion system	5	1	1	1	1	1			
Freezer (-20° C)	1							1	
Freezer (-70° C)	6	1	1	1	1	1	1		
G control centrifuge (8')	1								1
Gamma counter	5	1	1	1	1	1			
Guillotine	2							1	1
Hand wash facility	8	1	1	1	1	1	1	1	1
Hematocrit centrifuge	7	1	1	1	1	1	1	1	
Hematology analyzer	6	1	1	1	1	1	1		
Hematology kit	5	1	1	1	1	1			
Implanted biotelemetry	6	1	1	1	1	1	1		
Intravenous fluids	2		1		1				
Mass measure, small	2							1	1
Mass spectrometer	1						1		
Micro computer system	1							1	
Microscope, compound	6	1	1	1	1	1		1	
Microscope, dissecting	1								1
Multi purpose work bench	8	1	1	1	1	1	1	1	1
Radioactive tracer kit	5	1	1	1	1	1			
Refrigerator (4° C)	5	1	1	1	1	1			
Rhesus monkey food	6	1	1	1	1	1	1		
Rhesus monkey habitat	6	1	1	1	1	1	1		
Rhesus monkey water	6	1	1	1	1	1	1		
Rhesus restraint	6	1	1	1	1	1	1		
Rodent food	2							1	1
Rodent module	2							1	1
Rodent restraint	1							1	
Rodent water	2							1	1
SLR 35mm camera	1							1	
Sonomicrometer	6	1	1	1	1	1	1		
Surgery/dissection kit	1								1
Trash compactor	8	1	1	1	1	1	1	1	1
Veterinary kit	6	1	1	1	1	1	1		
Video camera, recorder, supplies	6	1	1	1	1	1		1	
Video microscope adaptor	1							1	
Xenon gas exchange system	1						1		

Cardiovascular System

D. CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEM (CELSS)

RATIONALE FOR CELSS EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR CELSS

CELSS EXPERIMENT TITLES

CELSS EXPERIMENT DESCRIPTIONS

CELSS EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

CELSS

RATIONALE FOR CELSS EXPERIMENTS ON SPACE STATION

A bioregenerative human life support system will be necessary for long-duration, manned spaceflight and planetary bases because of the inability to transport sufficient single-use life-support resources from Earth. This system is frequently described as a Controlled Ecological Life Support System (CELSS) and will be required to recycle human and animal wastes and produce oxygen and food as is done in our Earth environment.

These systems appear to be theoretically feasible, but the science and engineering understanding required to build them is not yet complete. United States' efforts in this area need to be expanded because competitive research and development is proceeding steadily in the Soviet Union and has begun in both Europe and Japan.

It will be important to effectively utilize data from the Plant Physiology discipline to maximize oxygen and food production in plants and ensure that any detrimental effects of spaceflight are minimized by appropriate countermeasures. The plant growth techniques developed during CELSS studies have a high probability of providing significant improvements in Earth-based agriculture via technology transfer.

PRIORITIZED SCIENCE OBJECTIVES FOR CELSS

- CL-1 Determine the microgravity conditions for optimizing the productivity of plants for CELSS applications. (Red Book-None)
Experiments: CL-A, B, C, D, K
- CL-2 Identify and evaluate the effectiveness of countermeasures to overcome the effects of microgravity on plant development and productivity. (Red Book-None)
Experiments: CL-A, B, D, F, G
- CL-3 Determine and evaluate the effects of spaceflight conditions on the interactions among the organisms and other components of a CELSS. (Red Book-None)
Experiments: CL-A, B, D, E, H, I, J, K

CELSS EXPERIMENT TITLES

Code	Title	Objective
CL-A	Optimization of Plant Nutrient and Water Supply Systems THIS EXPT ALSO LISTED AS PL-A	CL-1, CL-2, CL-3 (PL-1, PL-2, PL-3)
CL-B	Optimization of Plant Support and Orientation Mechanisms for Use in Microgravity THIS EXPT ALSO LISTED AS PL-B	CL-1, CL-2, CL-3 (PL-1, PL-2, PL-3)
CL-C	Multiple-Generation Plant Growth THIS EXPT ALSO LISTED AS PL-C	CL-1 (PL-1, PL-2)
CL-D	Mechanisms for Control of Atmospheric Gas Concentrations and Temperature in Microgravity THIS EXPT ALSO LISTED AS PL-H	CL-1, CL-2, CL-3 (PL-1, PL-2, PL-3)
CL-E	Effect of Organic Volatiles Produced by the Stress of Microgravity on Plant Metabolism	CL-3
CL-F	Evaluation of Light as a Means of Orienting Plant Growth in Microgravity	CL-2
CL-G	Evaluation of Centrifugation as a Means of Orienting Plant Growth in Microgravity	CL-2
CL-H	Microbial/Plant Interactions in Microgravity	CL-3
CL-I	Allelochemical Production under Microgravity	CL-3
CL-J	Growth of Multi-Species Plant Populations in Microgravity	CL-3
CL-K	Algal Growth in Microgravity	CL-1, CL-3

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: CELSS CL-A. (NOTE: This experiment duplicates Plant Physiology experiment PL-A.)
 - B. Science Objectives: CL-1, CL-2, CL-3 (PL-1, PL-2, PL-3).
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Optimization of Plant Nutrient and Water Supply Systems.
2. **PURPOSE/HYPOTHESIS:** To determine the optimal method for supplying nutrients and water to plants in microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This information is required to grow plants for conducting experiments in microgravity.
4. **APPROACH:**
 - A. Number/Type Specimens: 10 groups of 10-15 plants per group. Various plants (*Arabidopsis*, lettuce, wheat).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Whole plants harvested at weekly intervals.
Postflight: Dry weights of plant tissue.
 - C. Sample Analysis:
In-flight: None.
Postflight: Chemical composition of plant tissue.
 - D. Experiment Controls:
Although flight controls would not be required for all experiments, the best microgravity methods would ultimately have to be compared with a 1-g centrifuge control.
Ground-based: Controls for all methods tested.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, freezer, 1-g centrifuge (at some point).
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 25 hr.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:
 - A. Discipline/ Expt. Code: CELSS CL-B. (NOTE: This experiment duplicates Plant Physiology experiment PL-B.)
 - B. Science Objectives: CL-1, CL-2, CL-3 (PL-1, PL-2, PL-3).
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Optimization of Plant Support and Orientation Mechanisms for Use in Microgravity.
2. PURPOSE/HYPOTHESIS: To identify the optimal methods for holding and orienting plants in microgravity.
3. PROGRAM RATIONALE/JUSTIFICATION: This information is required to grow plants for conducting experiments.
4. APPROACH:
 - A. Number/Type Specimens: 10 groups of 10-15 plants per group. Various plants (*Arabidopsis*, lettuce, wheat, pine).
 - B. Measurements/Samples:

Preflight: None.

In-flight: Whole plants harvested at weekly intervals, and videomonitoring of plant growth.

Postflight: Dry weights of plant tissue.
 - C. Sample Analysis:

In-flight: None.

Postflight: Chemical analysis of plant tissue.
 - D. Experiment Controls:

In-flight: 1-g centrifuge control.

Ground-based: Controls for all methods.
5. SPACE STATION RESOURCE REQUIREMENTS:
 - A. Special Equipment (other than common items): Plant habitat, freezer, 1-g centrifuge, and plant habitat videomonitor.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 35 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: CELSS CL-C. (NOTE: This experiment duplicates Plant Physiology experiment PL-C.)
 - B. Science Objectives: CL-1 (PL-1, PL-2).
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Multiple-Generation Plant Growth.
2. **PURPOSE/HYPOTHESIS:** To evaluate the growth of plants over two generations under space-flight conditions.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Multiple-generation capabilities are required for plant use in CELSS, and are desirable for plant experiments.
4. **APPROACH:**
 - A. Type/Number Specimens: 2 groups of 50 plants per group. *Arabidopsis*.
 - B. Measurements/Samples:
In-flight: Telemonitoring.
Postflight: Analysis of a portion of space-grown seeds by growing them on Earth.
 - C. Sample Analysis:
In-flight: Biomass determination.
Postflight: Biomass determination.
 - D. Experiment Controls:
In-flight: 1-g centrifuge control.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat and videomonitor, and 1-g centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 10 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: CELSS CL-D. (NOTE: This experiment duplicates Plant Physiology experiment PL-H.)
 - B. Science Objectives: CL-1, CL-2, CL-3 (PL-1, PL-2, PL-3).
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Mechanisms for Control of Atmospheric Gas Concentrations and Temperature in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To identify methods for control of atmospheric temperature and gas concentrations for plant growth experiments.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Control of atmospheric temperature and gas concentrations requires circulation of the atmosphere. Atmosphere movement induces gravitational forces on plants. Thus, control must be achieved with minimum atmospheric movement.
4. **APPROACH:**
 - A. Number/Type Specimens: 5 groups of 10-15 plants per group. Various plants (lettuce, wheat, soybean).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Atmospheric temperature and gas concentrations.
Postflight: Harvest plants at end of experiment.
 - C. Sample Analysis:
In-flight: None.
Postflight: Dry weights of plant tissue.
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat and centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**

A. Discipline/ Expt. Code: CELSS CL-E.

B. Science Objectives: CL-3.

C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Organic Volatiles Produced by the Stress of Microgravity on Plant Metabolism.

2. **PURPOSE/HYPOTHESIS:** Purpose: To determine the effect of organics released by plants under microgravitational stress on other plants. Hypothesis: Organic volatiles produced under microgravity will affect growth/behavior of other species of plants.

3. **PROGRAM RATIONALE/JUSTIFICATION:** Stable growth of plants requires knowledge of environment. Stress effects are diverse, but they can be predicted and countered.

4. **APPROACH:**

A. Number/Type Specimens: 10 each. Corn and wheat.

B. Measurements/Samples:

In-flight: Gas sampling (or gas chromatography analysis) of organics.

C. Sample Analysis:

In-flight: Analysis of gas samples and gas chromatography analysis of organics in gas space and in nutrient solutions.

D. Experiment Controls:

In-flight: Organic gas removal.

Ground-based: Primary control.

5. **SPACE STATION RESOURCE REQUIREMENTS:**

A. Special Equipment (other than common items): Plant habitat, gas chromatograph, and mass spectrometer.

B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 6 hr.

C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**

A. Discipline/ Expt. Code: CELSS CL-F.

B. Science Objectives: CL-2.

C. McDAC Expt. Ref. #/Title (orig. or modified): Evaluation of Light as a Means of Orienting Plant Growth in Microgravity.

2. **PURPOSE/HYPOTHESIS:** To determine whether light can be used as a countermeasure to microgravity in orienting plant growth.

3. **PROGRAM RATIONALE/JUSTIFICATION:** For CELSS utilization, plants must be properly oriented in the culture unit plant habitat. Light may provide an orientation mechanism that can substitute for gravity.

4. **APPROACH:**

A. Number/Type Specimens: 4 groups of 20-25 seedlings per group. Various plants (sunflower, corn, lettuce).

B. Measurements/Samples:

In-flight: Orientation and morphology of plants.

C. Sample Analysis:

In-flight: None.

D. Experiment Controls:

In-flight: 1-g centrifuge.

5. **SPACE STATION RESOURCE REQUIREMENTS:**

A. Special Equipment (other than common items): Plant habitat, 1-g centrifuge, and plant habitat videomonitor.

B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.

C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: CELSS CL-G.
 - B. Science Objectives: CL-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Evaluation of Centrifugation as a Means of Orienting Plant Growth in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine whether centrifugation at early stages of development can provide orientation cues for plants.
3. **PROGRAM RATIONALE/JUSTIFICATION:** For CELSS use plants must be oriented properly in the plant habitat. Centrifugation may provide an orientation cue that can substitute for gravity.
4. **APPROACH:**
 - A. Number/Type Specimens: Various plants (sunflower, wheat).
 - B. Measurements/Samples:
In-flight: Orientation and morphology of plants.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: 1-g controls on centrifuge.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, 1-g centrifuge, and plant habitat videomonitor.
 - B. Estimated Total Inflight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

CELSS

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: CELSS CL-H.
 - B. Science Objectives: CL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Microbial/Plant Interactions in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Purpose: To assure stable plant growth in microgravity.
Hypothesis: Microgravity will affect plant metabolism, and thus affect microbial populations associated with roots and other plant parts.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Microgravity is a stress which might affect long-range plant growth because of internal (metabolic) and external (adherent microbial) responses.
4. **APPROACH:**
 - A. Number/Type Specimens: 10 each. Rice, wheat, soy.
 - B. Measurements/Samples:
In-flight: Collection and analysis of microbial populations on selected plants.
Postflight: Collection and analysis of microbial populations on selected plants if not done in flight.
 - C. Sample Analysis:
In-flight: Analysis of microbial populations and correlation of plant growth with microbial growth.
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
Ground-based: Controls identical to in-flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Microbial analysis kit and freezer.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 7 hr.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: CELSS CL-I.
 - B. Science Objectives: CL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Allelochemical Production Under Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine whether allelochemicals produced by one plant species may affect a second species more than on Earth.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Allelochemicals are produced by many plants to inhibit competitors. Under microgravity, plants may be more severely affected by allelochemicals, thus interfering with some CELSS studies.
4. **APPROACH:**
 - A. Number/Type Specimens: 2 groups of 15 plants of each species. Tomato, lettuce.
 - B. Measurements/Samples:
In-flight: Photosynthetic gas exchange.
Postflight: Biomass measurements.
 - C. Sample Analysis:
In-flight: None.
Postflight: Chemical analysis of plant tissue and nutrient solution samples.
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat and 1-g centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 4 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: CELSS CL-J.
 - B. Science Objectives: CL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Growth of Multi-Species Plant Populations in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Purpose: To determine whether microgravity has an effect on the growth of mixed plant populations. Hypothesis: Mixing species of plants during growth will not affect individual growth attributes.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Long-term growth of plants is needed for human life support.
4. **APPROACH:**
 - A. Number/Type Specimens: 10 of each species. Tomato, wheat, lettuce.
 - B. Measurements/Samples:
In-flight: CO₂/O₂ exchange. Plant mass.
Postflight: Weight of plants.
 - C. Sample Analysis:
In-flight: None.
Postflight: Chemical analysis of plant tissues.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls identical to flight specimens.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 4 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:
 - A. Discipline/ Expt. Code: CELSS CL-K.
 - B. Science Objectives: CL-1, CL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Algal Growth in Microgravity (ARC Book exp. # 5).
2. PURPOSE/HYPOTHESIS: Purpose: To determine which environmental parameters required for optimal growth of algae are affected by microgravity. Hypothesis: Microgravity will affect nonbiological aspects of algal growth.
3. PROGRAM RATIONALE/JUSTIFICATION: Long-term biomass growth in microgravity.
4. APPROACH:
 - A. Number/Type Specimens: Micro-algae: *Chlorella*.
 - B. Measurements/Samples:
In-flight: Cell number and mass per unit volume; one 2-ml sample/5 hr and O₂/CO₂ exchange.
 - C. Sample Analysis:
In-flight: Cell chlorophyll content. Continuous CO₂/O₂ analysis.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls identical to flight specimens.
5. SPACE STATION RESOURCE REQUIREMENTS:
 - A. Special Equipment (other than common items): CO₂/O₂ analyzer and lab centrifuge, if possible.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEM (CELSS) HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE										
		CL A	CL B	CL C	CL D	CL E	CL F	CL G	CL H	CL I	CL J	CL K
Crew Time (hours/90 days)		25	35	10	2	6	2	2	7	4	4	5
Item												
Cell counter	1											1
Centrifuge, laboratory	1											1
Experiment control computer	11	1	1	1	1	1	1	1	1	1	1	1
Fixation kit	1								1			
Fluid handling kit	1									1		
Freezer (-20° C)	3	1	1						1			
Freezer, cryo (-196° C)	4	1	1	1							1	
Gas chromatograph	1					1						
Hand wash facility	11	1	1	1	1	1	1	1	1	1	1	1
Incubator	1								1			
Mass spectrometer	1					1						
Microbial analysis kit	1								1			
Multi purpose work bench	11	1	1	1	1	1	1	1	1	1	1	1
Plant gas supplies	11	1	1	1	1	1	1	1	1	1	1	1
Plant habitat	11	1	1	1	1	1	1	1	1	1	1	1
Plant harvesting kit	2	1						1				
Plant nutrient supply	11	1	1	1	1	1	1	1	1	1	1	1
Seed planting kit	10	1	1	1	1	1	1	1	1	1	1	
Spectrophotometer	1											1
Trash compactor	11	1	1	1	1	1	1	1	1	1	1	1
Variable-G centrifuge (13')	11	1	1	1	1	1	1	1	1	1	1	1
Video camera, recorder, supplies	4		1	1			1	1				

E. ENDOCRINOLOGY/FLUID AND ELECTROLYTES

RATIONALE FOR ENDOCRINOLOGY/FLUID AND ELECTROLYTES EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR ENDOCRINOLOGY/FLUID AND ELECTROLYTES

ENDOCRINOLOGY/FLUID AND ELECTROLYTES EXPERIMENT TITLES

ENDOCRINOLOGY/FLUID AND ELECTROLYTES EXPERIMENT DESCRIPTIONS

ENDOCRINOLOGY/FLUID AND ELECTROLYTES EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

RATIONALE FOR ENDOCRINOLOGY/FLUID AND ELECTROLYTE EXPERIMENTS ON SPACE STATION

Small experimental animals have been flown in space for relatively short durations (less than 30 days). A number of histological changes have been observed in these animals immediately postflight. Some of the changes noted were in the kidney and hypothalamus, two areas of the body that regulate salt and water metabolism. The importance of changes in central neuroendocrine tissues are not well understood.

In humans, exposure to weightlessness results in an increased excretion of salt (sodium and potassium) and water. The physiological mechanism that produces this change in response to microgravity is not well understood. Use of small mammals for salt and water balance studies during long-duration flights will allow investigators to determine whether these changes are due to alterations in 1) blood levels of fluid/electrolyte hormones, 2) glandular secretion or synthesis of these hormones, or 3) actions of these hormones on target organs such as the kidney. Long-duration spaceflight on the space station will provide investigators with an opportunity to answer these questions.

PRIORITIZED SCIENCE OBJECTIVES FOR ENDOCRINOLOGY/FLUID AND ELECTROLYTES

- E/FE-1 Determine the role of microgravity on central controllers of various physiological systems (neurochemistry, neural metabolism, single cell responses). (Red Book-Basic Animal Research/Gen-3)
Experiments: E/FE-A
- E/FE-2 Determine the effect of spaceflight on fluid and electrolyte balance by measuring food/water intake, urinary volume, and sodium and potassium concentrations. (Red Book-1)
Experiments: E/FE-A
- E/FE-3 Determine changes in fluid/electrolyte hormones during spaceflight by collecting appropriate plasma and tissue samples for measuring plasma hormones and conducting histological examinations. (Red Book-1, 2, 3)
Experiments: E/FE-A

ENDOCRINOLOGY/FLUID AND ELECTROLYTES EXPERIMENT TITLES

Code	Title	Objective
E/FE-A	Effect of Long-Term Spaceflight on Hormonal Regulation of Fluid and Electrolyte Balance in Rats	E/FE-1, 2, 3

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Endocrinology/Fluid and Electrolyte: E/FE-A.
 - B. Science Objectives: E/FE-1, E/FE-2, E/FE-3.
 - C. McDAC Expt. Ref. #/Title (Orig. or modified): Effect of Long-Term Spaceflight on Hormonal Regulation of Fluid and Electrolyte Balance in Rats.
2. **PURPOSE/HYPOTHESIS:** To determine effect of long-term spaceflight on the hormonal regulation of fluid and electrolyte balance in rats.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Spaceflight produces fluid/electrolyte changes in humans that cannot be explained by our present knowledge of fluid/electrolyte physiology. If rats show similar disturbances in fluid/electrolyte metabolism, then a more detailed investigation of basic mechanisms could be made.
4. **APPROACH:**
 - A. Number/Type Specimens: 48 male Sprague-Dawley rats, 150-200 grams.
 - B. Measurements/Samples:

Preflight: Day 0: sacrifice 12 rats for baseline data (blood electrolyte and hormone level).
In-flight: +2 wk, 7-day balance, sacrifice final day of study for tissue collection, 12 rats (6 zero g, 6 controls 1 g); +4 wk, 7-day balance, sacrifice on final day of study, 12 rats (6 zero g, 6 controls 1 g); +8 wk, 7-day balance, sacrifice on final day of study 12 rats (6 zero g, 6 controls 1 g); +12 wk, 7-day balance, sacrifice on final day of study, 12 rats (6 zero g, 6 controls 1 g).
 - C. Sample Analysis:

In-flight: Measure food/water intake and urine volume during balance period.
Postflight: Analysis of blood plasma for Na⁺/K⁺, osmolarity, hormones (ADH, ANP, PRA); measure urinary electrolytes: Na⁺/K⁺ and hormones.
 - D. Experiment Controls:

In-flight: 1-g centrifuge controls.
Ground-based: 48 control rats must be housed in identical cages or research animal holding facility (RHAF).
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Metabolism cages for quantitative collection of urine and feces during the 7-day balance periods (for both microgravity and 1-g flight animals).
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 145 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

ENDOCRINOLOGY/FLUID AND ELECTROLYTES HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE
		E/FE A
Crew time (hr/90 day)		145
Item		
Cage cleaner	1	1
Centrifuge, laboratory	1	1
Fixation kit	1	1
Freezer (-20° C)	1	1
G control centrifuge (8')	1	1
Guillotine	1	1
Hand wash facility	1	1
Hematology kit	1	1
Multi-purpose work bench	1	1
Rodent food	1	1
Rodent metabolic module	1	1
Rodent module	1	1
Rodent water	1	1
Trash compactor	1	1

F. EXOBIOLOGY/SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (SETI)

RATIONALE FOR EXOBIOLOGY/SETI EXPERIMENTS ON SPACE STATION

a) PRIORITIZED SCIENCE OBJECTIVES FOR EXOBIOLOGY

EXOBIOLOGY EXPERIMENT TITLES

EXOBIOLOGY EXPERIMENT DESCRIPTIONS

b) PRIORITIZED SCIENCE OBJECTIVES FOR SETI

SETI EXPERIMENT TITLES

SETI EXPERIMENT DESCRIPTIONS

EXOBIOLOGY/SETI EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

RATIONALE FOR EXOBIOLGY/SETI EXPERIMENTS ON SPACE STATION

The primary objective of the Exobiology discipline is the study of the origin, evolution, and distribution of life and life-related molecules throughout the universe. This includes the history of biogenic elements from star formation through chemical evolution into present-day living systems, and the pathways of extraterrestrial prebiotic organic chemistry in chemical evolution.

The Exobiology/SETI program can be divided into three classes of space station experiments:

1. Observational

The use of attached or platform-mounted telescopes to observe the interstellar medium, stellar nebulae, and other galaxies for information about the biogenic elements and molecules.

The Search for Extraterrestrial Intelligence (SETI) is the only practical way at the present to find other civilizations around other stars. The program plan is to scan the microwave frequency window with radio telescopes and sophisticated signal-processing equipment looking for narrow-band features that might represent artificial signals radiating from other civilizations.

2. Nondestructive Cosmic Dust Collection

The collection and study of primordial materials that have been preserved under the physical conditions associated with their orbits since their separation from comets, asteroids, or interstellar clouds, will provide information on the cosmic evolution of biogenic elements and their compounds, as well as elucidate the pathways taken by biogenic materials from their origins in stars to their incorporation into some of the earliest objects formed in the solar system, including the Earth. The Nondestructive Cosmic Dust Collector would be attached to the space station or platform.

3. In Situ Microgravity Laboratory Experiments

The origins of the constituents of interstellar clouds, comets, meteorites, and interplanetary dust involves interactions among gases and grains in space. Experiments capable of yielding insight into the nature of these processes are of interest to both the Exobiology and Planetary Science areas.

Other in situ experiments include the survival and possible movement of microorganisms in the conditions of space (panspermia).

PRIORITIZED SCIENCE OBJECTIVES FOR EXOBIOLOGY/SETI

a) Exobiology

- ES/EX-1 Nondestructively collect cosmic dust particles that represent primitive solar system and interstellar materials. Chemically analyze the collected cosmic dust particles for biogenic elements (C, H, O, N, P, S) and compounds (water, CO₂, and organics), to provide knowledge on the chemical and physical evolution of the solar system and the origin of life. (Red Book-1)
Experiments: ES/EX-A
- ES/EX-2 Study the formation, growth, and accretion of dust grains and their interactions with interstellar gases, to trace the history of organic matter in the primitive solar system and evaluate the significance of abiologically produced organic matter in the evolution of terrestrial planets. (Red Book-3)
Experiments: ES/EX-B
- ES/EX-3 Study the physical and chemical reactions in the nucleus and on the surface of an artificial icy comet during exposure to the microgravity, vacuum, and radiation environment of space to determine the contribution of comets to the distribution of volatile biogenic elements and compounds to the planets. Remote observation of artificial comets to provide information on the composition of the primordial solar nebula. (Red Book-2)
Experiments: ES/EX-C
- ES/EX-4 Conduct astronomical spectrophotometric observations of planetary atmospheres, comets, molecular cloud cores, diffuse interstellar clouds, evolved stars, nebulae, and other galaxies in order to understand the origin and evolution of biogenic elements and compounds in the universe. (Red Book-2)
Experiments: ES/EX-E
- ES/EX-5 Evaluate the hypothesis that life could have been carried to Earth from outer space (panspermia) by studying the factors that contribute to the ejection of microbes from planets into space, and their survival in the space environment. (Red Book-7)
Experiments: ES/EX-D
- ES/EX-6 Evaluate the reactive properties of naturally occurring high-velocity oxygen atoms in the space environment. (Red Book-6)
Experiments: ES/EX-F

EXO BIOLOGY/SETI EXPERIMENT TITLES

a) Exobiology

Code	Title	Objective
ES/EX-A	Collection and Analysis of Cosmic Dust Particles	ES/EX-1
ES/EX-B	Study the Formation, Growth and Interaction of Dust Grains and Gases Involved in Solar System Evolution	ES/EX-2
ES/EX-C	Study the Physical and Chemical Reactions of the Biogenic Elements in an Artificial Icy Comet During Exposure to Space	ES/EX-3
ES/EX-D	Study the Survival of Microbes in Space	ES/EX-5
ES/EX-E	Use of Infrared Astronomy to Search for Biogenic Elements and Compounds	ES/EX-4
ES/EX-F	Neutral Atomic Oxygen Reactions	ES/EX-6

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: a) Exobiology ES/EX-A.
 - B. Science Objectives: ES/EX-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Collection and Analysis of Cosmic Dust Particles.
2. **PURPOSE/HYPOTHESIS:** Nondestructively decelerate and collect cosmic dust (1-10 μm size). Determine mass, velocity, and direction to determine origin of particle (solar system or interstellar). Analyze particles for biogenic elements and organic compounds.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Direct sampling of particles that represent primitive solar system material (comets) and interstellar dust particles for biogenic elements (C, H, O, N, P, S) and compounds (water, carbon dioxide, and organics) would contribute to knowledge about the chemical and physical evolution of the solar system and the origin of life.
4. **APPROACH:**
 - A. Number/Type Specimens: N/A.
 - B. Measurements/Samples:
In-flight: Electronic analysis of dust-particle trajectory to determine origin, mass, and velocity of the particles.
 - C. Sample Analysis:
Postflight: Collector foil would be replaced about once each year and returned to the ground for chemical analysis of particles collected.
 - D. Experiment Controls: N/A.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Cosmic dust collector (about 4 m diameter x 20 m long) attached to space station truss; electronic controls in Science Laboratory Module—needs 10-kW electrical; weight \approx 1200 kg.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): EVA to exchange collector foil once each year.
 - C. Experiment Site: LSRF: Attached Payload: \checkmark Platform:

Exobiology/SETI: a) Exobiology

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: a) Exobiology ES/EX-B.
 - B. Science Objectives: ES/EX-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Study the Formation, Growth, and Interaction of Dust Grains and Gases Involved in Solar System Evolution.
2. **PURPOSE/HYPOTHESIS:** Study the processes by which dust grains nucleate, condense, and grow while interacting with gases present in the solar nebula and interstellar clouds to produce organic matter. Study how grains accrete to form the larger planetesimal-sized objects thought to have been the building blocks of planets.
3. **PROGRAM RATIONALE/JUSTIFICATION:** In situ experiments are necessary to study the interaction of dust grains and gases to trace the history of organic matter in the primitive solar system and to evaluate the input of abiologically produced organic matter into the primordial atmosphere of the terrestrial planets.
4. **APPROACH:**
 - A. Number/Type Specimens: N/A.
 - B. Measurements/Samples:
In-flight: Monitoring of coagulation and accretion of dust grains with various gases.
Postflight: Same as in-flight.
 - C. Sample Analysis:
Postflight: Study the structure, morphology, chemistry and other characteristics of the grains.
 - D. Experiment Controls: N/A.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Microgravity gas-grain reaction facility; one rack size for reaction chamber and instrumentation.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 48 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform: poss

Exobiology/SETI: a) Exobiology

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:

A. Discipline/ Expt. Code: Exobiology/SETI: a) Exobiology ES/EX-C.

B. Science Objectives: ES/EX-3.

C. McDAC Expt. Ref. #/Title (orig. or modified): Study the Physical and Chemical Reactions of the Biogenic Elements in an Artificial Icy Comet During Exposure to Space.

2. PURPOSE/HYPOTHESIS: Expose an artificial comet (50% fluffy ice and 50% dust) to microgravity, vacuum, and radiation environment of space and monitor surface reactions. After time, the residual material would be retrieved for analysis.

3. PROGRAM RATIONALE/JUSTIFICATION: Comets are believed to be the best example of undifferentiated solar system material, and contain up to 50% volatile materials including carbon dioxide and water. As the comet approaches the Sun, the sublimation of water ice creates an outflowing stream of gases which carry dust particles from the comet's surface. Study of the physical and chemical processes on a comet surface while passing close to Earth would provide information about the contribution of comets to the distribution of biogenic elements to the planets and their relation to the origin of life.

4. APPROACH:

A. Number/Type Specimens: N/A.

B. Measurements/Samples:

In-flight: Observational monitoring of surface of the artificial comet. Collection of residual material (after 30 days) and return to ground for analysis.

C. Sample Analysis:

Postflight: Analysis of residual material.

D. Experiment Controls: N/A.

5. SPACE STATION RESOURCE REQUIREMENTS:

A. Special Equipment (other than common items): Foaming device to produce artificial comet "snowball."

B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 4 hr.

C. Experiment Site: LSRF: Attached Payload: √ Platform: poss

Exobiology/SETI: a) Exobiology

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: a) Exobiology ES/EX-D.
 - B. Science Objectives: ES/EX-5.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Study the Survival of Microbes in Space.
2. **PURPOSE/HYPOTHESIS:** Study the factors that contribute to the ejection of microbes from planets into space and govern their survival.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Evaluate the hypothesis that life can be carried to Earth from outer space. Study the survival of microorganisms in the space environment.
4. **APPROACH:**
 - A. Number/Type Specimens: Various microorganisms.
 - B. Measurements/Samples:
In-flight: Expose a number of terrestrial microorganisms to the radiation, vacuum, microgravity, and temperature extremes of space, and determine their survival. Return samples for analysis.
 - C. Sample Analysis:
Postflight: Analysis of exposed microorganisms.
 - D. Experiment Controls: N/A.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: Attached Payload: poss Platform: ✓

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: a) Exobiology ES/EX-E.
 - B. Science Objectives: ES/EX-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Use of Infrared Astronomy to Search for Biogenic Elements and Compounds.
2. **PURPOSE/HYPOTHESIS:** Conduct astronomical spectrophotometric observations of planetary atmospheres, comets, molecular cloud cores, diffused interstellar clouds, evolved stars, nebulae, and other galaxies for biogenic elements and compounds.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Cooperate with the astronomical community to conduct observations on the chemistry of biogenic elements and compounds in order to understand their origin and the evolution of the universe.
4. **APPROACH:**
 - A. Number/Type Specimens: N/A.
 - B. Measurements/Samples:
In-flight: Measurements at infrared wavelengths for detection of biogenic elements and compounds.
 - C. Sample Analysis: N/A.
 - D. Experiment Controls: N/A.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): SIRTf infrared telescope—same as astrophysics community telescope.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: Attached Payload: √ Platform: √

Exobiology/SETI: a) Exobiology

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:
 - A. Discipline/ Expt. Code: Exobiology/SETI: a) Exobiology ES/EX-F.
 - B. Science Objectives: ES/EX-6.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Neutral Atomic Oxygen Reactions.
2. PURPOSE/HYPOTHESIS: To study the chemistry of high-velocity oxygen atoms in Earth orbit and evaluate their applicability in the preparation of unusual oxygen-containing compounds and in laser systems.
3. PROGRAM RATIONALE/JUSTIFICATION: The glow on the windward-facing surfaces of the space shuttle shows that the differentiated velocity of about 8 km/sec between the shuttle and the ambient oxygen atoms is sufficient to overcome the activation energy for reactions between ground state (neutral) oxygen atoms and various elements and compounds.
4. APPROACH:
 - A. Number/Type Specimens: N/A.
 - B. Measurements/Samples:
In-flight: Measure oxygen atom reaction rates and activation energies in a reaction cell through which the high-velocity atoms flow with measurement downstream by spectroscopy.
 - C. Sample Analysis: N/A.
 - D. Experiment Controls: N/A.
5. SPACE STATION RESOURCE REQUIREMENTS:
 - A. Special Equipment (other than common items): Oxygen atom reaction cell.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: Attached Payload: ☒ Platform:

Exobiology/SETI: a) Exobiology

PRIORITIZED SCIENCE OBJECTIVES FOR EXOBIOLOGY/SETI
b) SETI

- ES/SE-1 Use a large space antenna to search space for microwave radio signals that may have been generated by intelligent life. (Red Book-Post IOC)
Experiments: ES/SE-A, G
- ES/SE-2 Measure the radio frequency interference environment (1-100 GHz) in orbits below Geosynchronous. (Red Book-None)
Experiments: ES/SE-B, G
- ES/SE-3 Study the efficacy and longevity of thin-film shields for elimination of radio frequency interference to the SETI antenna. (Red Book-None)
Experiments: ES/SE-C, G
- ES/SE-4 Develop and test technologies needed to perform microwave searches of the closest solar-type stars. (Red Book-None)
Experiments: ES/SE-D, E, F, G

EXO BIOLOGY/SETI EXPERIMENT TITLES

b) SETI

Code	Title	Objective
ES/SE-A	High Frequency Orbital SETI Observing Program	ES/SE-1
ES/SE-B	Determination of the Radio Frequency Interference in Low Earth Orbit	ES/SE-2
ES/SE-C	Thermal and Radiation Shield for SETI Antenna	ES/SE-3
ES/SE-D	Microwave Frequency Scanning and Processing of Artificial Signals Radiating from Extraterrestrial Civilizations	ES/SE-4
ES/SE-E	SETI Phased-Array Antenna Development	ES/SE-4
ES/SE-F	SETI Noise Cancellation Experiment	ES/SE-4
ES/SE-G	SETI by Observing the Microwave Radio Signals Coming from Space	ES/SE-1-4

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:

A. Discipline/ Expt. Code: Exobiology/SETI: b) SETI ES/SE-A.

B. Science Objectives: ES/SE-1.

C. McDAC Expt. Ref. #/Title (orig. or modified): High Frequency Orbital SETI Observing Program.

2. PURPOSE/HYPOTHESIS: Use large space antenna to search for microwave radio signals from outer space that may have been generated by intelligent life. This search would concentrate on the range from 10-100 GHz and would include the nearest 10^4 solar-type stars.

3. PROGRAM RATIONALE/JUSTIFICATION: If a suitable Radio Frequency Interference (RFI)-free environment can be identified at or below geosynch, a modest cost SETI observing program could be conducted above the Earth's atmosphere.

4. APPROACH: Measure microwaves in 10-100 GHz range of closest solar type stars in search for intelligent signals.

5. SPACE STATION RESOURCE REQUIREMENTS:

A. Special Equipment (other than common items): Automated spectrum surveillance analyzer and 3-m antenna. Large microwave antenna (20-100 m diameter) with receiver tunable in range from 10-100 GHz and signal processing instrumentation.

B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.

C. Experiment Site: LSRF: Attached Payload: ☒ Platform: poss

NOTE: All SETI experiments are Post-IOC.

Exobiology/SETI: b) SETI

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: b) SETI ES/SE-B.
 - B. Science Objectives: ES/SE-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Determination of the Radio Frequency Interference in Low Earth Orbit.
2. **PURPOSE/HYPOTHESIS:** Sensitive SETI signal detection systems may be severely hampered by the presence of radio frequency interference arriving at groundbased antennas from terrestrial, over-flying or orbital transmitters. There may exist an orbit or combination of orbits at some altitude at or below geosynch that provides a more benign interference environment for SETI.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Published data on the assignment of space and actual implementation of frequency allocation in geosynch and the antenna patterns of orbital transmitters pointed earthward and terrestrial transmitters pointed skyward are insufficient to determine whether any orbits below geosynch will offer improvement over the terrestrial interference environment. An on-orbit survey must be conducted.
4. **APPROACH:** An automated spectrum surveillance analyzer capable of scanning 1 to 100 GHz (see TDA Report 42-82 page 173) serving as the receiver for a 3-m antenna will be used for on-board detection and characterization of RFI events. This will involve a low data rate for downlink and ground-based analysis.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): SLM or platform; automated spectrum surveillance analyzer, construction (or shuttle lift) of 3-m antenna, on-board processors and power supply, standard telemetry downlink, OMV or other mechanism for increasing orbit altitude.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: √ Attached Payload: poss Platform: √

NOTE: All SETI experiments are Post-IOC.

Exobiology/SETI: b) SETI

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: b) SETI ES/SE-C.
 - B. Science Objectives: ES/SE-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Thermal and Radiation Shield for SETI Antenna.
2. **PURPOSE/HYPOTHESIS:** Unless noise subtraction schemes involving low Earth orbit antennas prove feasible, SETI antennas operated at or above geosynchronous orbit will require backward shielding from RFI generated at lower altitudes.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This shielding may be incorporated into the structure of the antenna, but a free-flying shield would provide additional benefit. It could act as a thermal shield allowing the surface of the antenna to be maintained with greater ease since thermal gradients should no longer result when the antenna is repointed.
4. **APPROACH:** Experiments on or near the space station should be conducted to establish the efficacy and longevity of thin film shields with thickness on the order of a few skin depths. Multiple component designs may be required with the inner shield blocking the spillover from the edges of the outer shield. A suitable on-orbit construction technique will be sought.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Thin film shield material and construction equipment. Robotic remote radiometers for measuring the near-field performance of the shield configuration without perturbing the field.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: Attached Payload: √ Platform: √

NOTE: All SETI experiments are Post-IOC.

Exobiology/SETI: b) SETI

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: b) SETI ES/SE-D.
 - B. Science Objectives: ES/SE-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Microwave Frequency Scanning and Processing of Artificial Signals Radiating from Extraterrestrial Civilizations.
2. **PURPOSE/HYPOTHESIS:** Learn how to fabricate and assemble in space shielded large (diameter = 100 m and up) ultralight antennas for use in the free space microwave window (0.3 to 300 GHz).
3. **PROGRAM RATIONALE/JUSTIFICATION:** Earth-based SETI monitoring of the microwave spectrum is severely blocked by man-made signals and atmospheric absorption. The extraterrestrial location, microgravity environment, and solar and terrestrial shielding provided on the space station will be ideal for the installation and operation of ultralight, very large antennas for this purpose.
4. **APPROACH:** The implementation of a SETI microwave system includes:
 - 1) Assemble antennas, power, and related control and signal processing systems.
 - 2) Systems and operational procedures testing.
 - 3) EVA-servicing robot testing.
 - 4) Space station-based data relay system testing.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Antenna; antenna control system; EVA servicing robot and control system; signal processing and data relay system; antenna assembly kit.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: Attached Payload: √ Platform: √

NOTE: All SETI experiments are Post-IOC.

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: b) SETI ES/SE-E.
 - B. Science Objectives: ES/SE-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): SETI Phased-Array Antenna Development.
2. **PURPOSE/HYPOTHESIS:** A controllable phased-array may effectively discriminate against RFI and may be used without expending fuel for antenna pointing and station keeping.
3. **PROGRAM RATIONALE/JUSTIFICATION:** A small phased-array will be flown in geosynchronous or higher orbit to test the ability to track and point this antenna without active station keeping. Careful attention must be paid to its design in order to enhance its ability to reject RFI.
4. **APPROACH:** A phased-array antenna of at least two 10-m flat elements will be launched from the space station into geosynchronous or higher orbit. Laser signals from each element of the antenna will send data as well as timing information to a receiver on the space station. It will be determined whether the antenna can be accurately tracked and phased under control from the station. Data analysis will be conducted from the ground.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Tracking and control computer. Wide-band laser receiving system attached to space station. On-orbit construction capabilities for 10 m flat antenna elements (or lift allotment on shuttle if that proves more cost effective). Phasing harnesses, RF receivers, solar panels for backside of antenna elements constructed on Earth and lifted for assembly near the station.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: Attached Payload: Platform: √

NOTE: All SETI experiments are Post-IOC.

1. EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:
 - A. Discipline/ Expt. Code: Exobiology/SETI: b) SETI ES/SE-F.
 - B. Science Objectives: ES/SE-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): SETI Noise Cancellation Experiment.
2. PURPOSE/HYPOTHESIS: An omnidirectional antenna near the Earth may provide effective RFI cancellation when used in conjunction with the SETI antenna in high orbit.
3. PROGRAM RATIONALE/JUSTIFICATION: A test in space of such an RFI cancelling system is necessary. The difference in the arrival phase of a signal at the omnidirectional antenna and the deep space antenna must be known precisely. Only if both antennas are in orbit can the degradation known to be caused by travel of signals through the Earth's atmosphere be eliminated.
4. APPROACH: An antenna and receiver flown on the space station with omnidirectional characteristics and small collecting area will be used to subtract strong RFI signals from data collected in deep space by the experimental SETI phased-array elements or another antenna design. Data from the station will be beamed to the ground and then combined with deep space data.
5. SPACE STATION RESOURCE REQUIREMENTS:
 - A. Special Equipment (other than common items): Theodolite measure of relative position of omnidirectional antenna with respect to some fiducial of the space station whose location in space is known to a few mm accuracy. Omnidirectional receiver covering 1 to 30 GHz range. Wideband data link to ground.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: Attached Payload: √ Platform: √

NOTE: All SETI experiments are Post-IOC.

Exobiology/SETI: b) SETI

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Exobiology/SETI: b) SETI ES/SE-G.
 - B. Science Objectives: ES/SE-1, ES/SE-2, ES/SE-3, ES/SE-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): SETI by Observing the Microwave Radio Signals Coming from Space.
2. **PURPOSE/HYPOTHESIS:** Use large space antenna to search for microwave radio signals from outer space that may have been generated by intelligent life. This search would concentrate on the range from 10 -100 GHz and would include the nearest 10^4 solar-type stars.
3. **PROGRAM RATIONALE/JUSTIFICATION:**
4. **APPROACH:** Measure radio frequency interference environment (1-100 GHz frequency) in orbits below geosynch. Study efficiency and longevity of thin shields for elimination of radio frequency interference to SETI antenna. Measure microwaves in 10-100 GHz range for closest solar type stars.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Automated spectrum surveillance analyzer and 3-m antenna. Large microwave antenna (20-100 m diameter) with receiver tunable in range from 10-100 GHz and signal processing instrumentation.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: Attached Payload: ☒ Platform: ☒

NOTE: All SETI experiments are Post-IOC.

Exobiology/SETI: b) SETI

EXO BIOLOGY/SETI EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

A. Hardware Requirements

The experiments associated with Exobiology/SETI are hardware-intensive, require minimal support by the crew, and can be designed as unpressurized payloads attached to the space station or on free-flying platforms. Therefore, this section is not completed in a manner similar to the other disciplines which define laboratory hardware requirements. Definition of this hardware will, of course, be required at a future time using a different format.

B. Crew-Time Requirements

Procedures and crew time required for conducting experiments for these two disciplines are unique for the reasons stated in paragraph A, above. It is anticipated that these experiments will require crew support primarily for installation and activation of the highly automated hardware and perhaps retrieval of samples and some data at experiment termination. Minimal crew support for housekeeping, servicing or experiment procedures will be required on a daily or weekly basis. Future analysis of these procedures must await clearer definition of experiment hardware.

G. HEMATOLOGY

RATIONALE FOR HEMATOLOGY EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR HEMATOLOGY

HEMATOLOGY EXPERIMENT TITLES

HEMATOLOGY EXPERIMENT DESCRIPTIONS

HEMATOLOGY EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

RATIONALE FOR HEMATOLOGY EXPERIMENTS ON SPACE STATION

A significant effect of the spaceflight environment on blood-forming tissue is a postflight reduction in the number of circulating red blood cells. Because this is associated with a decrease in plasma volume, it appears similar to the loss of whole blood which occurs during a mild hemorrhage. This decrease, observed in human subjects, appears early in spaceflight and is progressive. The body's normal sensing mechanisms do not seem to sense this decrease and there is no compensatory response. This effect is not understood, but it may be due to a combined increased trapping of red blood cells by the spleen and decreased bone marrow function.

It is not known whether this effect will decrease exercise tolerance of astronauts in-flight and whether the bone marrow will respond normally in the case of a life-threatening hemorrhage. Interestingly, there is no known similar effect in the presence of normal gravity. It has been suggested, therefore, that the causative mechanisms are dissimilar to any known causes of anemia.

Major questions to be answered include:

- 1) Will this response occur in animals to a similar degree to that seen in humans? Can a good animal model be identified?
- 2) Can treatments be devised to allow the bone marrow to respond to hemorrhage normally?
- 3) Will the bone marrow respond to erythropoietin and increase the production of red cells?
- 4) Is the circulating blood deficient in young red blood cells (reticulocytes)?

This phenomenon is an important physiological observation because it has not been observed in normal gravity and if the bone marrow function is abnormal, it could have important consequences to anyone who might be injured in space.

PRIORITIZED SCIENCE OBJECTIVES FOR HEMATOLOGY

- HE-1 Determine sequential changes in red cell mass and erythropoietin levels. (Red Book1)
 Experiments: HE-B, HE-E
- HE-2 Do serial bone marrow examinations on animal models. (Red Book 2)
 Experiments: HE-C
- HE-3 Determine possible role of splenic sequestration of RBCs as a possible cause of the decrease
 in red cell mass. (Red Book 3)
 Experiments: HE-D
- HE-4 Examine in vivo response to erythropoietin in microgravity. (Red Book 4)
 Experiments: HE-E
- HE-5 Determine in-flight changes in P-50 of RBCs. (Red Book 5)
 Experiments: HE-F
- HE-6 Reevaluate the possible occurrence of subtle hematological effects as a result of procedures
 requiring prebreathing of 100% oxygen before EVAs. (Red Book 6)
 Experiments: HE-A

HEMATOLOGY EXPERIMENT TITLES

Code	Title	Objective
HE-A	Effect of 100% Oxygen on Red Cell Production and Lifespan	HE-6
HE-B	Determine Sequential Changes in Red Blood Cell Mass (RCBM) and Erythropoietin (EP) Levels	HE-1
HE-C	Examine the Effect of Microgravity on Blood and Bone Marrow Colony-Forming Cells: CFU-S, CFU-E, BFU-E, etc.	HE-2
HE-D	Examine the Effect of Microgravity on Splenic Sequestration of RBCs as a Possible Cause of the Decrease in Red Blood Cell Mass (RCBM)	HE-3
HE-E	Examine the Effect of Microgravity on the Bone Marrow's Response to Erythropoietin (EP)	HE-1, HE-4
HE-F	Examine the Effect of Microgravity on the Bone Marrow's Response to Hemorrhage	HE-5

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Hematology HE-A.
 - B. Science Objectives: HE-6.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of 100% Oxygen on Red Cell Production and Lifespan.
2. **PURPOSE/HYPOTHESIS:** Purpose: To determine whether red cell production rate and life span are changed by increased oxygen atmosphere in 0 g.
Hypothesis: Increased oxygen will stimulate conversion of yellow marrow to red marrow and will influence production of red cells.
3. **PROGRAM RATIONALE/JUSTIFICATION:** EVA will be a significant activity in the space station, and will require periods of breathing increased oxygen. This may influence production and lifespan of red cells as a result of changes in the bone marrow.
4. **APPROACH:**
 - A. Number/Type Specimens: 50 adult rats (500 grams).
 - B. Measurements/Samples:
Preflight: Injection of stable iron (Fe-58) tracers.
In-flight: Injection of stable iron (Fe-58) tracers. Kill some animals and preserve at 15, 30, 60, 90, and 120 days. Draw blood.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: None.
Postflight: Tracer analysis by neutron activation or mass spectrometer.
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
Ground-based: Same as in-flight specimens.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): 1-g centrifuge in-flight.
 - B. Estimated Total In-flight Crew Time (hr/90 day based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Hematology HE-B.
 - B. Science Objectives: HE-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Determine Sequential Changes in Red Blood Cell Mass (RBCM) and Erythropoietin (EP) Levels.
2. **PURPOSE/HYPOTHESIS:** To determine whether changes in EP relate to the changes in RBCM.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Humans invariably decrease the size of their circulating red blood cell mass during exposure to microgravity. This decrease has the potential of decreasing exercise capacity and, if associated with a profound decrease in erythropoietin, may result in a delayed response to hemorrhage from injury.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 laboratory rats (250-300 grams).
 - B. Measurements/Samples:
Preflight: RBCM, EP serum level, and routine hematology.
In-flight: Same as preflight.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: RBCM.
Postflight: EP from specimens obtained pre- and in-flight.
 - D. Experiment Controls:
In-flight: 1-g controls on 12 rats fed and maintained at weight of flight animals.
Ground-based: Same as in-flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Gamma counter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 4 rats done each mo, 6 hr crew time three times = 18 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Hematology HE-C.
 - B. Science Objectives: HE-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Examine the Effect of Microgravity on Blood and Bone Marrow Colony-Forming Cells: CFU-S, CFU-E, BFU-E, etc.
2. **PURPOSE/HYPOTHESIS:** The decreased number of reticulocytes found in crew members' in-flight and postflight blood suggests that bone marrow activity has decreased.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Humans invariably decrease the size of their circulating red blood cell mass during exposure to microgravity. This decrease has the potential of decreasing exercise capacity and, if associated with a profound decrease in erythropoietin, may result in a delayed response to hemorrhage from injury.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 laboratory rats (250-300 grams).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Bone marrow and spleen.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of samples collected in-flight.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 30 control rats fed and maintained at weight of flight animals.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 rats done each wk, 2 hr crew time weekly = 24 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Hematology HE-D.
 - B. Science Objectives: HE-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Examine the Effect of Microgravity on Splenic Sequestration of RBCs as a Possible Cause of the Decrease in Red Blood Cell Mass (RBCM).
2. **PURPOSE/HYPOTHESIS:** The decreased RBCM found in crew members' postflight blood specimens suggests that RBCs have been lost by early splenic sequestration because the size of the loss and its rapidity could not be explained only by decreased bone marrow function.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Humans invariably decrease the size of their circulating RBCM during exposure to microgravity. This decrease has the potential of decreasing exercise capacity and, if associated with a profound decrease in erythropoietin, may result in a delayed response to hemorrhage from injury.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 laboratory rats (250-300 grams).
 - B. Measurements/Samples:
Preflight: None.
In-flight: The animals will be injected with labeled RBCs. At various post-injection times, the animals will be sacrificed and the total splenic concentration of the tagged RBCs will be measured.
Postflight: None.
 - C. Sample Analysis:
In-flight: Total splenic concentration of the tagged RBCs measured.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 24 control rats fed and maintained at weight of flight animals.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Gamma counter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 rats done each wk, 4 hr crew time weekly = 48 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Hematology HE-E.
 - B. Science Objectives: HE-1, HE-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Examine the Effect of Microgravity on the Bone Marrow's Response to Erythropoietin (EP).
2. **PURPOSE/HYPOTHESIS:** To determine whether changes in EP relate to the changes in red blood cell mass (RBCM). To determine whether pharmacological doses of EP will correct this defect in RBCM during exposure to microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Humans invariably decrease the size of their circulating RBCM during exposure to microgravity. This decrease has the potential of decreasing exercise capacity and, if associated with a profound decrease in EP, may result in a delayed response to hemorrhage from injury.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 laboratory rats (250-300 grams).
 - B. Measurements/Samples:
Preflight: EP injections, RBCM all animals.
In-flight: Same as preflight.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: RBCM.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 12 control rats fed and maintained at weight of flight animals.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Gamma counter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 40 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Hematology HE-F.
 - B. Science Objectives: HE-5.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Examine the Effect of Microgravity on the Bone Marrow 's Response to Hemorrhage.
2. **PURPOSE/HYPOTHESIS:** If changes in erythropoietin (EP) cause the decrease in red blood cell mass (RBCM) found in microgravity, then an animal's response to hemorrhage may not be normal.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Humans invariably decrease the size of their circulating RBCM during exposure to microgravity. This decrease has the potential of decreasing exercise capacity and, if associated with a profound decrease in EP, may result in a delayed response to hemorrhage from injury.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 laboratory rats (250-300 grams).
 - B. Measurements/Samples:
Preflight: RBCM all animals.
In-flight: Same as preflight.
Postflight: Same as preflight. All animals will receive phlebotomies.
 - C. Sample Analysis:
In-flight: Routine hematologic analysis.
Postflight: Same as in-flight.
 - D. Experiment Controls: 12 control rats fed and maintained at weight of flight animals.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Gamma counter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 40 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

HEMATOLOGY HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE					
		HE A	HE B	HE C	HE D	HE E	HE F
Crew time (hr/90 day)		TBD	18	24	48	40	40
Item							
Cage cleaner	6	1	1	1	1	1	1
Centrifuge, laboratory	1		1				
Centrifuge, refrigerated	3		1			1	1
Fluid handling kit	1						1
Fluid infusion system	1	1					
Freezer (-20° C)	1		1				
G control centrifuge (5')	1	1					
Gamma counter	4		1		1	1	1
Guillotine	4	1	1	1	1		
Hand wash facility	6	1	1	1	1	1	1
Hematocrit centrifuge	4	1	1			1	1
Hematology analyzer	4	1	1			1	1
Hematology kit	3		1			1	1
Histology kit	1			1			
Mass measure, small	2		1				1
Mass spectrometer	1					1	
Multi-purpose work bench	6	1	1	1	1	1	1
Nonradioactive tracer kit	1	1					
Radioactive tracer kit	3		1			1	1
Refrigerator (4° C)	1	1					
Rodent food	6	1	1	1	1	1	1
Rodent metabolic module	1	1					
Rodent module	6	1	1	1	1	1	1
Rodent water	6	1	1	1	1	1	1
Surgery/dissection kit	1			1			
Trash compactor	6	1	1	1	1	1	1

Hematology

H. IMMUNOLOGY

RATIONALE FOR IMMUNOLOGY EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR IMMUNOLOGY

IMMUNOLOGY EXPERIMENT TITLES

IMMUNOLOGY EXPERIMENT DESCRIPTIONS

IMMUNOLOGY EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

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Immunology

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RATIONALE FOR IMMUNOLOGY EXPERIMENTS ON SPACE STATION

Immunology experiments conducted to date have yielded preliminary results suggesting that the spaceflight environment can produce impairment of several types of immune responses. Changes have been seen in the areas of cell-mediated immune function and interferon production. These changes raise concerns about possible immunosuppression developing in individuals undergoing long-term spaceflight. Unfortunately, no controlled studies have been conducted to determine whether spaceflight produces an increased susceptibility to infection. Indeed, controlled human studies of this type are extremely difficult to conduct.

The first science objective should be to determine whether a good animal model shows an increased susceptibility to infection with bacteria and viruses immediately postflight. If this is substantiated, an intensive effort to study mechanisms and protective measures should begin. If no change in susceptibility to infection is observed, then this fundamental question will have been addressed and additional experiments should be given lower priority.

Additional investigations to be conducted if spaceflight-related immunosuppression is demonstrated include immune responses to vaccines at the cellular and immunoglobulin levels, reversibility of effects on interferon production, and the effects on ontological development of the immune response.

All experiments proposed require no special in-flight procedures. No special hardware nor introduction of infectious agents are required during spaceflight.

PRIORITIZED SCIENCE OBJECTIVES FOR IMMUNOLOGY

- IM-1 Determine whether spaceflight produces a functional impairment in the ability of the immune system to respond to specific viral and bacterial challenges, including: changes in leukocyte function (chemotaxis, adherence, and phagocytic abilities), bone marrow leukocyte production, and B- and T-lymphocyte response to mitogenic challenges. (Red Book 1)
Experiments: IM-A, IM-B, IM-C
- IM-2 Determine the nature of the effect of spaceflight on innate and acquired immunity, including characterization of the time course and magnitude of the changes that occur in differential leukocyte counts and immunoglobulin concentrations. (Red Book 4)
Experiments: IM-D
- IM-3 Determine whether the effects of spaceflight on the immune system are completely reversible upon return to 1 g, or if repeated spaceflight exposures will produce a cumulative effect that might compromise crew health in space or after return to 1 g. (Red Book 5)
Experiments: IM-E
- IM-4 Determine ability to generate a secondary response after long-term exposure to 0 g for both individual specimens and multigenerational studies. (Red Book 6)
Experiments: IM-F

IMMUNOLOGY EXPERIMENT TITLES

Code	Title	Objective
IM-A	Effect of Spaceflight on Susceptibility to Bacterial and Viral Infections on Return to Earth	IM-1
IM-B	Effect of Spaceflight on Immune Responses to Vaccines	IM-1
IM-C	Effect of Spaceflight on Immune Response: Mitogen Response of Leukocytes Postflight	IM-1
IM-D	Effect of Spaceflight on Immunoglobulin Production	IM-2
IM-E	Reversibility of Potential Alterations of Immune Response Caused by Spaceflight	IM-3
IM-F	Effect of Spaceflight on Developmental Immunology	IM-4

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Immunology IM-A.
 - B. Science Objectives: IM-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight on Susceptibility to Bacterial and Viral Infections on Return to Earth.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of spaceflight on susceptibility to viral and bacterial infection on return to Earth.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Spaceflight has been shown to alter components of the immune response (e.g., interferon and T-cell function). Does this have practical health-related significance in altering susceptibility to life-threatening infectious disease?
4. **APPROACH:**
 - A. Number/Type Specimens: 24 mice (12 to be infected postflight, 12 control).
 - B. Measurements/Samples:
Preflight: None.
In-flight: None.
Postflight: Half of the mice were infected with one LD-50 of *Salmonella typhimurium*; half were infected with one LD-50 of encephalomyocarditis virus immediately upon return to Earth.
 - C. Sample Analysis:
In-flight: None.
Postflight: Determine survival times of infected mice.
 - D. Experiment Controls:
In-flight: Uninfected mice.
Ground-based: Infected and uninfected mice; prior determination of LD-50.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 8 1/2 hr.
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Immunology IM-B.
 - B. Science Objectives: IM-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight on Immune Response to Vaccines.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of spaceflight on the ability to mount an immune response to commonly used vaccines.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Spaceflight has been shown to alter components of the immune response (e.g., interferon and T-cell function). Does this have practical health-related significance in altering immune responses to vaccines? Important in controlling resistance to life-threatening infectious disease.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 mice dedicated to the study.
 - B. Measurements/Samples:
Preflight: Immunize 8 animals with nontoxic tetanus toxoid, 8 with nontoxic diphtheria toxoid, and 8 with killed complete Freund's adjuvant.
In-flight: None.
Postflight: Assess animals' immune response to antigens listed above.
 - C. Sample Analysis:
In-flight: None.
Postflight: Enzyme-linked immune assays for rodents' immune response to tetanus and diphtheria toxoid, and ear skin testing for response to Freund's adjuvant.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Mice immunized and assessed on same basis as flight animals.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 16 hr.
 - C. Experiment site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Immunology IM-C.
 - B. Science Objectives: IM-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight on Immune Response; Mitogen Response of Leukocytes Postflight.
2. **PURPOSE/HYPOTHESIS:** To determine whether spaceflight produces a functional impairment in ability of immune responses to respond to specific challenges.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Spaceflight has been shown to alter the ability of leukocytes to respond to antigens or mitogens. In a completely controlled study, the extent and depth of these alterations will be determined.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 rodents (inbred).
 - B. Measurements/Samples:
Preflight: None.
In-flight: None.
Postflight: Measure phagocytosis and blastogenesis.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of immunological function.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Rodents tested in same fashion as flight animals at several time intervals to establish baseline.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 8 1/2 hr.
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Immunology IM-D.
 - B. Science Objectives: IM-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight on Immunoglobulin Production
2. **PURPOSE/HYPOTHESIS:** To determine the effect of spaceflight on immunoglobulin production.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Spaceflight has shown no effect on immunoglobulin production, but the only studies done thus far have been short term. This study will determine effects of long-term spaceflight on immunoglobulin production.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 rodents.
 - B. Measurements/Samples:
Preflight: Quantitative and qualitative immunoglobulin levels in sera.
In-flight: None.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: None.
Postflight: Quantitative and qualitative immunoglobulin levels in sera.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Rodents for same type of analysis as flight rodents.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 8 1/2 hr.
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Immunology IM-E.
 - B. Science Objectives: IM-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Reversibility of Potential Alterations of Immune Response Caused by Spaceflight.
2. **PURPOSE/HYPOTHESIS:** To determine duration of spaceflight-induced alterations in immune response.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Spaceflight has been shown to alter components of immune responses; is this a transient or permanent alteration?
4. **APPROACH:**
 - A. Number/Type Specimens: 24 rodents.
 - B. Measurements/Samples:

Preflight: Immunize 8 animals with nontoxic tetanus toxoid, 8 with nontoxic diphtheria toxoid, and 8 with killed complete Freund's adjuvant.

In-flight: None.

Postflight: Assess animals' immune response to antigens listed above. 12 animals infected with one LD-50 of *Salmonella typhimurium*; 12 infected with one LD-50 of encephalomyocarditis virus immediately upon return to Earth. Measure phagocytosis and blastogenesis on all animals.
 - C. Sample Analysis:

In-flight: None.

Postflight: Enzyme-linked immune assays for rodent's immune response to tetanus and diphtheria toxoid, ear skin testing for response to Freund's adjuvant; survival times; analysis of immunological function.
 - D. Experiment Controls:

In-flight: None.

Ground-based: Rodents tested in same fashion as flight animals at several time intervals to establish baseline.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 16 hr.
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Immunology IM-F.
 - B. Science Objectives: IM-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight on Developmental Immunology.
2. **PURPOSE/HYPOTHESIS:** To determine how the immune response develops in animals born in space.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Spaceflight has been shown to alter components of mature immune systems. This experiment would clarify the effects of spaceflight on the developing immune response.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 rodents born in space for development biology program.
 - B. Measurements/Samples:

Preflight: Immunize 8 animals with nontoxic tetanus toxoid, 8 with nontoxic diphtheria toxoid, and 8 with killed complete Freund's adjuvant.

In-flight: None.

Postflight: Assess animals' immune response to antigens listed above. 12 animals infected with one LD-50 of *Salmonella typhimurium*; 12 infected with one LD-50 of encephalomyocarditis virus immediately upon return to Earth. Measure phagocytosis and blastogenesis on all animals.
 - C. Sample Analysis:

In-flight: None.

Postflight: Enzyme-linked immune assays for rodent's immune response to tetanus and diphtheria toxoid, ear skin testing for response to Freund's adjuvant; survival times; analysis of immunological function.
 - D. Experiment Controls:

In-flight: None.

Ground-based: Rodents born on same day as flight animals treated in same fashion.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): No additional time over developmental biology requirement.
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

IMMUNOLOGY HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE					
		IM A	IM B	IM C	IM D	IM E	IM F
Crew time (hr/90 day)		8.5	16	8.5	8.5	16	0
Item							
Cage cleaner	6	1	1	1	1	1	1
Development module	1						1
Hand wash facility	6	1	1	1	1	1	1
Multi-purpose work bench	6	1	1	1	1	1	1
Rodent food	6	1	1	1	1	1	1
Rodent module	6	1	1	1	1	1	1
Rodent water	6	1	1	1	1	1	1
Trash compactor	6	1	1	1	1	1	1

I. METABOLIC REGULATION

RATIONALE FOR METABOLIC REGULATION EXPERIMENTS ON SPACE STATION

- a) **PRIORITIZED SCIENCE OBJECTIVES FOR SLEEP/PERFORMANCE**
SLEEP/PERFORMANCE EXPERIMENT TITLES
SLEEP/PERFORMANCE EXPERIMENT DESCRIPTIONS
 - b) **PRIORITIZED SCIENCE OBJECTIVES FOR TEMPERATURE**
REGULATION/METABOLISM
TEMPERATURE REGULATION/METABOLISM EXPERIMENT TITLES
TEMPERATURE REGULATION/METABOLISM EXPERIMENT DESCRIPTIONS
 - c) **PRIORITIZED SCIENCE OBJECTIVES FOR CELL BIOLOGY**
CELL BIOLOGY EXPERIMENT TITLES
CELL BIOLOGY EXPERIMENT DESCRIPTIONS
 - d) **PRIORITIZED SCIENCE OBJECTIVES FOR CIRCADIAN RHYTHMS**
CIRCADIAN RHYTHMS EXPERIMENT TITLES
CIRCADIAN RHYTHMS EXPERIMENT DESCRIPTIONS
- METABOLIC REGULATION EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS**

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Metabolic Regulation

RATIONALE FOR METABOLIC REGULATION EXPERIMENTS ON SPACE STATION

The force of gravity at the Earth's surface is unchanging; therefore, the weight-to-mass ratio is perhaps the most constant of all environmental factors experienced by life. One of the many homeostatic adaptations of living organisms to this force is the ability to convert substrates in the biosphere to energy for physical support, movement, and behavior. These adaptive systems shape many of the actions and behaviors of the organism, yet all metabolic changes must ultimately be manifested at the cellular level. Collectively, this broad area of research is referred to as "metabolic regulation," and includes studies of the magnitude, efficiency, regulation, and control of energy utilization.

The microgravity of the spaceflight environment provides a major environmental change which is unique in evolutionary history. Physiological—including metabolic—changes in space have been documented for the past 25 years. Included are changes in fluid balance, electrolyte loss, negative nitrogen balance, adjustments in sleep patterns, and changes in body temperature. However, the etiology of these and other biomedical abnormalities associated with spaceflight have not yet been explained. For the first time, the space station will provide sufficient durations of microgravity to conduct studies which can answer these basic questions.

In understanding the effects of microgravity on metabolic regulation, several levels of study need to be considered. Initially, metabolism, both organismal and cellular, should be evaluated for changes in type, magnitude, and time constants. Subsequently, neural and endocrine control mechanisms regulating metabolism should be studied.

Finally, the totality of metabolic responses and regulation of energy utilization can be studied dynamically as performance and behavior at the organismal level. Two physiological systems important in this regard are those regulating circadian rhythms and sleep. The efficiency, magnitude, and timing of energy utilization combine to describe an individual's behavior and performance. This information is essential for long-term spaceflights.

In summary, the gravitational influences on metabolic regulation can be studied most efficiently from a combination of approaches. In this section, metabolic regulation experiments have been divided into four areas: Sleep/Performance, Temperature Regulation/Metabolism; Cell Biology, and Circadian Rhythms.

PRIORITIZED SCIENCE OBJECTIVES FOR METABOLIC REGULATION

a) Sleep/Performance

- MR/SP-1 Is the total sleep time, distribution of sleep states, or entrainment of the 24-hr sleep-wake cycle influenced by microgravity? (Red Book-Basic Animal Research/Sleep-1)
Experiments: MR/SP-A
- MR/SP-2 What is the effect of sleep deficits (if any) on crew performance, efficiency, and mental and physical health? (Red Book-Basic Animal Research/Sleep-2)
Experiments: MR/SP-B
- MR/SP-3 Is the latency of sleep onset, measured at different times of day (with and without sleep deprivation) influenced by microgravity? (Red Book-Basic Animal Research/Sleep-3)
Experiments: MR/SP-C

METABOLIC REGULATION EXPERIMENT TITLES

a) Sleep/Performance

Code	Title	Objective
MR/SP-A	Effects of Altered Gravity on Sleep Patterns	MR/SP-1
MR/SP-B	Sleep and Performance Deficits in Microgravity	MR/SP-2
MR/SP-C	Multiple Sleep Latency Tests	MR/SP-3

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: a) Sleep/Performance MR/SP-A.
 - B. Science Objectives: MR/SP-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Altered Gravity on Sleep Patterns.
2. **PURPOSE/HYPOTHESIS:** Sleep (total time, distribution and time of sleep states, and entrainment of the 24-hr sleep-wake cycle) will be altered by changes in gravity. This study will examine the gravity threshold and kinetics of that response.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Sleep is altered in microgravitational and hypergravitational environments. The sleep system is of critical importance to performance, mental health, and physical well-being. Changes in sleep need to be defined, understood, and corrected, if necessary.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 squirrel monkeys. (Some parallel work can and should be done on humans.)
 - B. Measurements/Samples:

Preflight: Control studies, including protocol same as in-flight.

In-flight: Continuous collection for 72 hr on wk 1, 2, 4, 8, and 12 of EEG, EMG, EOG (electrophysiological parameters necessary for deep-state determination); brain temperature; feeding; and drinking. Experiments should be performed at fractional gravity as well as microgravity. Data stored and sent to ground for analysis.

Postflight: Follow-up studies, including protocol same as in-flight.
 - C. Sample Analysis:

In-flight: None.

Postflight: None.
 - D. Experiment Controls:

In-flight: None.

Ground-based: Preflight and postflight controls at 1 g and >1 g.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Data system and variable-g centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Metabolic Regulation: a) Sleep/Performance

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: a) Sleep/Performance MR/SP-B.
 - B. Science Objectives: MR/SP-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Sleep and Performance Deficits in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Sleep will be disturbed during spaceflight and this disturbance will affect crew performance and well-being. Performance needs to be assessed as a function of schedules, sleep, and space adaptation.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Sleep is altered during spaceflight and by work-schedule manipulation. To improve tolerance of microgravity and optimize work schedules on the space station, multiple performance criteria need to be evaluated.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 Rhesus monkeys.
 - B. Measurements/Samples:
Preflight: Control studies, including protocol same as in-flight.
In-flight: Continuously measured for 48 hr on wk 1, 2, 4, 8, and 12: operant task learning, cognition, sleep, and temperature.
Postflight: Follow-up studies, including protocol same as in-flight.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Preflight and postflight controls at 1 g and >1 g.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Restraint system; and performance evaluation facility.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 10 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Metabolic Regulation: a) Sleep/Performance

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: a) Sleep/Performance MR/SP-C.
 - B. Science Objectives: MR/SP-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Multiple Sleep Latency Tests.
2. **PURPOSE/HYPOTHESIS:** Sleep distribution and consolidation is influenced by microgravity. To test this sensitivity to altered gravity, animals are exposed to 60 min of darkness every 120 min.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The consolidation of sleep in the 24-hr day is influenced by gravity. Changes in sleep latency, duration, and type in the dark will provide an understanding of sleep regulation and homeostasis in space.
4. **APPROACH:**
 - A. Number/Type Specimens: 4-6 squirrel monkeys or Rhesus monkeys. (Could be done on humans in a strictly controlled environment.)
 - B. Measurements/Samples:
Preflight: Control studies, including protocol same as in-flight.
In-flight: Collect data for 24 hr on wk 1, 3, 7, and 11 (sleep parameters, temperature, feeding, and drinking).
Postflight: Follow-up studies, including protocol same as in-flight.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Preflight and postflight controls at 1 g and >1 g.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Data system.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 8 hr.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

PRIORITIZED SCIENCE OBJECTIVES FOR METABOLIC REGULATION

b) Temperature Regulation/Metabolism

- MR/TM-1 Is the regulation of body temperature and metabolism influenced by microgravity? (Red Book-Basic Animal Research/Temp. Reg.-1)
 Experiments: MR/TM-A, E
- MR/TM-2 Are the influences of homeostatic stressors (i.e., exercise, ambient temperature, pyrogen) on body temperature regulation influenced by microgravity? (Red Book-Basic Animal Research/Temp. Reg.-2)
 Experiments: MR/TM-C, E
- MR/TM-3 Are the central or peripheral thermoreceptor gains or thresholds influenced by microgravity? (Red Book-Basic Animal Research/Temp. Reg.-3)
 Experiments: MR/TM-D
- MR/TM-4 What is the role of body size (i.e., scaling) on physiological systems such as metabolism and body composition? (Red Book-Basic Animal Research/Temp. Reg.-4)
 Experiments: MR/TM-B

METABOLIC REGULATION EXPERIMENT TITLES

b) Temperature Regulation/Metabolism

Code	Title	Objective
MR/TM-A	Temperature Regulation and Metabolism During Spaceflight	MR/TM-1
MR/TM-B	Scaling Influences on Homeostatic Responses to Gravitational Unloading	MR/TM-4
MR/TM-C	Homeostasis as Influenced by Gravity Levels	MR/TM-2
MR/TM-D	Thermosensitivity of Primates in Space	MR/TM-3
MR/TM-E	Study of Metabolic Balance in Rodents in Microgravity	MR/TM-1, MR/TM-2

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: b) Temperature Regulation/Metabolism MR/TM-A.
 - B. Science Objectives: MR/TM-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): MB5/Temperature Regulation and Metabolism During Spaceflight.
2. **PURPOSE/HYPOTHESIS:** To test the hypothesis that temperature regulation and metabolism are altered a) in space and b) by fractional gravity, and to examine the gravity threshold for response.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Temperature regulation is a relatively simple physiological system which is sensitive to gravity and is an indication of many other systemic responses in an organism.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 squirrel monkeys.
 - B. Measurements/Samples:

Preflight: Control studies, including protocol same as in-flight.

In-flight: Measure body and brain temperatures, and gas metabolism and heat loss continuously for 72 hr on wk 1, 2, 4, 6, 8, 10, and 12. Measurement of body mass, urine, feces, plasma volume, total body water, red blood cell mass, and extracellular volume, and renal function tests should be conducted in association with the 72-hr tests. Data collected at 0 g and fractional gravity, stored and downlinked. Data includes wet sample masses.

Postflight: Follow-up studies, including protocol same as in-flight.
 - C. Sample Analysis:

In-flight: Chemical compositions.

Postflight: TBD.
 - D. Experiment Controls:

In-flight: 1-g centrifuge controls.

Ground-based: Ground-based controls and hypergravity studies.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Physiological monitoring/data systems, mass spectrometer, whole-body, gradient-layer calorimeter; metabolism chamber (capable of collecting and separating urine and feces); variable-g centrifuge; telemetry; and mass measuring device.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Metabolic Regulation: b) Temperature Regulation/Metabolism

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: b) Temperature Regulation/Metabolism MR/TM-B.
 - B. Science Objectives: MR/TM-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Scaling Influences on Homeostatic Responses to Gravitational Unloading.
2. **PURPOSE/HYPOTHESIS:** Scaling (body size) is related to the physiological responsiveness of an organism to altered gravity.
3. **RATIONALE/JUSTIFICATION:** Scaling influences will be determined across a range of species size (0.1 - 100 grams). Thresholds and kinetics of responses will be determined.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 each human, Rhesus monkey, squirrel monkey, rat, and mouse.
 - B. Measurements/Samples:
Preflight: Baseline studies.
In-flight: Measurements determined continuously for 48 hr at wk 1, 2, 3, 4, 6, 8, and 12.
Postflight (nonhuman): Body temperature, intermediary and gas metabolism, and body composition.
 - C. Sample Analysis:
In-flight: TBD.
Postflight: TBD.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Preflight at 1 g and >1 g, postflight measurements.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Physiological monitoring/data systems, mass spectrometer, metabolism chamber (capable of collecting and separating urine and feces), variable-g centrifuge, telemetry, and mass measuring device.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 40 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Metabolic Regulation: b) Temperature Regulation/Metabolism

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: b) Temperature Regulation/Metabolism MR/TM-C.
 - B. Science Objectives: MR/TM-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Homeostasis as Influenced by Gravity Levels.
2. **PURPOSE/HYPOTHESIS:** Test the regulation of body temperature at microgravity, and fractional gravity, as stimulated by pyrogen, exercise, light, and/or ambient temperature.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Homeostatic systems, such as temperature regulation, respond to external stimulation by changing controlled variables to maintain the regulated variable(s). This experiment tests the efficacy of such a regulatory schema at altered gravity levels, particularly the influence on the controlled variables.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 squirrel monkeys.
 - B. Measurements/Samples:
Preflight: Baseline studies.
In-flight: Measurements of brain temperature, gas metabolism, and heat loss collected at wk 1, 2, 4, 8, and 12, stored and downlinked.
Postflight: TBD.
 - C. Sample Analysis:
In-flight: None.
Postflight: TBD.
 - D. Experiment Controls:
In-flight: TBD.
Ground-based: Preflight at 1 g and >1 g, postflight studies.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Physiological monitoring/data systems, mass spectrometer, gradient-layer calorimeter, metabolism chamber, variable-g centrifuge, restraint system, and telemetry.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 15 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Metabolic Regulation: b) Temperature Regulation/Metabolism

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: b) Temperature Regulation/Metabolism MR/TM-D.
 - B. Science Objectives: MR/TM-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Thermosensitivity of Primates in Space.
2. **PURPOSE/HYPOTHESIS:** To examine the thermosensitivity of the hypothalamus and its sensitivity to variable gravity. Alterations in gain, thermosensitivity, or coupling mechanisms of central neural temperature sensors will alter temperature regulation.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Altered regulation of body temperature results from gravitational influence on segments of the regulatory system. This experiment examines the input portion of this system and sensor integration with the balance of the system.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 squirrel monkeys.
 - B. Measurements/Samples:
Preflight: Baseline studies.
In-flight: Data collected on wk 1, 2, 4, 8, and 12, stored and downlinked for analysis (brain temperature, gas metabolism, heat loss).
Postflight: TBD.
 - C. Sample Analysis:
In-flight: None.
Postflight: Data analysis.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Preflight and postflight studies at 1 g and >1 g.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Physiological monitoring/data systems, mass spectrometer, gradient layer calorimeter, metabolism chamber, variable-g centrifuge, restraint system, and telemetry.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 hr.
 - C. Experiment site: LSRF: ☒ Attached Payload: Platform:

Metabolic Regulation: b) Temperature Regulation/Metabolism

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: b) Temperature Regulation/Metabolism MR/TM-E.
 - B. Science Objectives: MR/TM-1, MR/TM-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): MB1a / Study of Metabolic Balance in Rodents in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To test the hypothesis that temperature regulation and metabolism are altered a) in space and b) by fractional gravity, and to examine the gravity threshold for response.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Temperature regulation is a relatively simple physiological system which is sensitive to gravity and is an indication of many other systemic responses in an organism.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 mature laboratory rats (250 - 300 grams).
 - B. Measurements/Samples:

Preflight: Baseline studies.

In-flight: Measure body and brain temperatures, and gas metabolism and heat loss continuously for 72 hr on wk 1, 2, 4, 6, 8, 10, and 12. Measurement of body mass, urine, feces, plasma volume, total body water, red blood cell mass, extracellular volume, and renal function tests should be conducted in association with the 72-hr tests. Data collected at 0 g and fractional gravity, stored and downlinked. Data includes wet sample masses.

Postflight: TBD.
 - C. Sample Analysis:

In-flight: Chemical composition.

Postflight: TBD.
 - D. Experiment Controls:

In-flight: 1-g centrifuge.

Ground-based: Ground-based controls and hypergravity studies.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Physiological monitoring/data systems; mass spectrometer, whole-body, gradient-layer calorimeter, metabolism chamber (capable of collecting and separating urine and feces), variable-g centrifuge, telemetry, and mass-measuring device.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 hr.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

Metabolic Regulation: b) Temperature Regulation/Metabolism

PRIORITIZED SCIENCE OBJECTIVES FOR METABOLIC REGULATION

c) Cell Biology

- MR/CB-1 Determine the role/effect of microgravity on structure and function of organisms at the cellular level. (Red Book-Basic Animal Research/Gen-1)
 Experiments: MR/CB-A, B
- MR/CB-2 Determine the role/effect of microgravity on the energetics and metabolism of the organism at the cellular level. (Red Book-Basic Animal Research/Gen-1)
 Experiments: MR/CB-C
- MR/CB-3 Determine whether the physiological changes seen in space are due to changes in cellular regulation of receptors and transport. (Red Book-Basic Animal Research/Gen-1)
 Experiments: MR/CB-D
- MR/CB-4 Determine the role/effect of microgravity on growth and homeostasis of the organism at the cellular level. (Red Book-Basic Animal Research/Gen-1)
 Experiments: MR/CB-A

METABOLIC REGULATION EXPERIMENT TITLES

c) Cell Biology

Code	Title	Objective
MR/CB-A	Exocrine Function and Protein Secretion in Salivary Glands as Influenced by Microgravity	MR/CB-1, MR/CB-4
MR/CB-B	Molecular Mechanisms of Microgravity Effects—Baseline Data for Biotechnological Commercialization of Space	MR/CB-1
MR/CB-C	Mechanism of Cellular Receptor Changes Seen in Microgravity as Reflected by Associated Physiological Changes	MR/CB-2
MR/CB-D	Energy Utilization in Eukaryotic and Prokaryotic Cells in Microgravity	MR/CB-3

SEE ALSO:

R/D-BB Effect of Microgravity on Wound Healing

R/D-CC Effect of Spaceflight on Wound Healing

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Metabolic Regulation: c) Cell Biology MR/CB-A.
 - B. Science Objectives: MR/CB-1, MR/CB-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Exocrine Function and Protein Secretion in Salivary Glands as Influenced by Microgravity.
2. **PURPOSE/HYPOTHESIS:** Use of salivary glands for studying exocrine function and protein secretion . Assessing cellular ultrastructure and molecular mechanisms of action influenced by microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Measuring adaptational and homeostatic responses of beta adrenergic-stimulated cellular signal processing.
4. **APPROACH:**
 - A. Number/Type Specimens: Rodent salivary glands.
 - B. Measurements/Samples:
Preflight: Morphological and biochemical studies.
In-flight: Same as preflight.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: None.
Postflight: Microscopy and biochemistry.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Postflight recovery studies.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Liquid nitrogen fixative for electron microscopy.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

Metabolic Regulation: c) Cell Biology

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Metabolic Regulation: c) Cell Biology MR/CB-B.
 - B. Science Objectives: MR/CB-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Molecular Mechanisms of Microgravity Effects—Baseline Data for Biotechnological Commercialization of Space.
2. **PURPOSE/HYPOTHESIS:** Does cell function change in microgravity? Are there changes in cytoskeleton, endocytosis, or exocytosis? Are receptors expressed differently in space? Do the subcellular organelles change?
3. **PROGRAM RATIONALE/JUSTIFICATION:** The mechanisms of metabolic changes seen in microgravity remain unexplained. All metabolic changes are ultimately expressed at the cellular level. Changes in cellular function will be examined in vitro and in vivo.
4. **APPROACH:**
 - A. Number/Type Specimens: Muscle, bone lymphoma, kidney, genetically engineered bacteria, and yeast cell cultures are grown in 0 g and 1 g. (Note: Cell cultures begin preflight.)
 - B. Measurements/Samples:
Preflight: Begin cell cultures.
In-flight: 1) Cell samples are taken from incubator and frozen daily for 7 days (in triplicate).
2) Cells are grown at 0 g and 1 g.
Postflight:
 - C. Sample Analysis:
In-flight: None.
Postflight: Study of cytoskeleton, electron microscopy of organelles, endocytosis, and exocytosis. Cell production will be analyzed and genetically engineered bacteria growth will be evaluated.
 - D. Experiment Controls:
In-flight: TBD.
Ground-based: Controls will parallel in-flight experiments in 1 g.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): -70° freezer, CO₂ cell incubator, and multiwell culture plates for rapid sampling.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr per cell type studied.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

Metabolic Regulation: c) Cell Biology

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Metabolic Regulation: c) Cell Biology MR/CB-C.
 - B. Science Objectives: MR/CB-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Mechanism of Cellular Receptor Changes Seen in Microgravity as Reflected by Associated Physiological Changes.
2. **PURPOSE/HYPOTHESIS:** Physiologic responses seen in flight can be explained at the molecular level by measuring responses of cell receptors in microgravity (e.g., insulin, glucocorticoids, L-DOPA, PTH, etc.). Changes in receptors will be measured in target tissues and in cell lines. Transport of small molecules will also be measured.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Data from manned spaceflight have shown changes in glucocorticoids, insulin response, and bone and muscle metabolism. These changes could be explained by examining expression and activity of cellular receptors.
4. **APPROACH:**
 - A. Number/Type Specimens: Rat and human target tissue cells—isolated cells measuring transport and receptors (cultured cell lines).
 - B. Measurements/Samples:
Preflight: None.
In-flight: 1) Collect cell membrane for analysis of receptors after 1, 2, 4, 8, 16, 20, 30, and 40 days of flight. 2) Measure receptors and transport in cell lines at 0 and 1 g.
Postflight: None.
 - C. Sample Analysis:
In-flight: Analyze transport and cell receptors in cell culture.
Postflight: Analyze transport and cell receptors in cell culture.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls.
Ground-based: Controls will parallel flight experiments.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Micro-ultracentrifuge, -70° freezer, Polyiron, CO₂ incubator, and hardware for centrifuging and collection.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 4 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Metabolic Regulation: c) Cell Biology

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Metabolic Regulation: c) Cell Biology MR/CB-D.
 - B. Science Objectives: MR/CB-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Energy Utilization in Eukaryotic and Prokaryotic Cells in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Evidence from Spacelab 1 (SL-1) lymphocytes and from negative nitrogen balance in astronauts would suggest an increase in full energy utilization in microgravity. We would like to correlate product formation with energy utilization in cells.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Astronauts have a negative nitrogen balance in spaceflight despite a relatively high calorie intake. In addition, quiescent lymphocytes in SL-1 astronauts seemed to use the same energy as actively growing cells at 1 g. Both these anomalies of spaceflight could be explained by an increased energy requirement in microgravity.
4. **APPROACH:**
 - A. Number/Type Specimens: 3T3 cells, lymphocytes, rat muscle cells, HeLa fibroblasts and bioengineered *Escherichia coli* bacteria for product formation, grown at 0 g and 1 g.
 - B. Measurements/Samples:
Preflight: Culture growth.
In-flight: Collect samples over a 7-day period, at time of media change.
Postflight: TBD.
 - C. Sample Analysis:
In-flight: Analysis of cell number (doubling time), carbon atom utilization (glucoanalysis), and product formation from genetically engineered bacteria.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: 1-g controls.
Ground-based: Controls will parallel flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Coulter Counter, CO₂ incubator for 0 g and 1 g, -70° freezer, glucose analyzer, cell culture plates, and cell culture plate reader.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2.4 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

PRIORITIZED SCIENCE OBJECTIVES FOR METABOLIC REGULATION

d) Circadian Rhythms

- MR/CR-1 Are circadian rhythms of various physiological systems influenced by microgravity (i.e., period, phase, mean, amplitude)? (Red Book-Basic Animal Research/Circ. Rhythms-1)
Experiments: MR/CR-A
- MR/CR-2 How do the influences of microgravity affect crew performance and adaptability to work schedules? (Red Book-Basic Animal Research/Circ. Rhythms-2)
Experiments: MR/CR-B
- MR/CR-3 Are the timing influences of environmental synchronizers (temperature, light, gravity) affected by microgravity. If so, how (on receptors or central controllers)? (Red Book-Basic Animal Research/Circ. Rhythms-3)
Experiments: MR/CR-C
- MR/CR-4 What is the role of microgravity adaptation on cross-adaptation to other aspects (light, temperature, ambient pressure, etc.) of the environment? (Red Book-Basic Animal Research/Gen-5)
Experiments: MR/CR-C

METABOLIC REGULATION EXPERIMENT TITLES

d) Circadian Rhythms

Code	Title	Objective
MR/CR-A	Effects of Altered Gravity on Circadian Rhythms in Diurnal and Nocturnal Animals	MR/CR-1
MR/CR-B	The Impact of Microgravity and Fractional Gravity Loading on Behavior and Performance	MR/CR-2
MR/CR-C	Chronophysiological Response to Fractional Gravity Loads	MR/CR-3, 4

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: d) Circadian Rhythms MR/CR-A.
 - B. Science Objectives: MR/CR-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Altered Gravity on Circadian Rhythms in Diurnal and Nocturnal Animals.
2. **PURPOSE/HYPOTHESIS:** To establish the influence of microgravity and fractional gravitational load/thresholds on the circadian rhythms of diurnal and nocturnal animals. Use of light-dark cycles and constant light environment will be used to quantify the responses of the circadian timekeeping system.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is known that a given phase relationship between the environment (e.g., gravity, temperature, light cycles) and physiological systems is necessary for optimal homeostasis. The space station offers the opportunity to evaluate the influence of a unique environmental change (e.g., altered gravitational load) on special specific circadian parameters (phase, period, amplitude). These rates of change can be used to identify circadian clock mechanism changes.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 each (rodents, squirrel monkeys) at each gravitational level.
 - B. Measurements/Samples:
Preflight: Heart rate, body temperature, locomotor activity, water and food intake: measurements taken continuously for 90 days in vivarium cages.
In-flight: Same as preflight.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: None.
 - D. Experiment Controls:
In-flight: 1 g, pre/postflight measurements.
Ground-based: 1-g and hypergravity studies.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Variable-g centrifuge, and telemetry system.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 45 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: d) Circadian Rhythms MR/CR-B.
 - B. Science Objectives: MR/CR-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): The Impact of Microgravity and Fractional Gravity Loading on Behavior and Performance.
2. **PURPOSE/HYPOTHESIS:** To determine the gravitational threshold for performance tasks in rodents (memory) and primates (cognition, learning, performance, and vigilance) and to describe associated chronophysiological changes in two mammalian species (rodent, and primate). Correlations with work schedules and their effects on performance can then be evaluated.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Are there circadian rhythm alterations related to changes in performance during either short- or long-duration spaceflight? (Fabricant pp. 93-96). Circadian rhythm asynchrony impairs crew performance. This issue has yet to be scientifically evaluated in the space environment. Therefore, it is of some importance to quantitate the impact of various gravitational fields on performance.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 each (rodents, squirrel monkeys), performance-trained, fully instrumented; 6 each (rodents, squirrel monkeys) fully instrumented, not trained.
 - B. Measurements/Samples:
Preflight: Heart rate, body temperature, locomotor activity, feeding, and drinking. Performance testing during adaptation to microgravity and to fractional gravity loads delivered by an on-board variable-g centrifuge. Continuous sample measurements by data system.
In-flight: Same as preflight.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls.
Ground-based: On-and-off centrifuge (1 g and 2 g).
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Rodent and primate performance tests, variable-g centrifuge, and telemetry system.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Metabolic Regulation: d) Circadian Rhythms

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Metabolic Regulation: d) Circadian Rhythms MR/CR-C.
 - B. Science Objectives: MR/CR-3, MR/CR-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Chronophysiological Response to Fractional Gravity Loads.
2. **PURPOSE/HYPOTHESIS:** The effects of provocative stimuli (e.g., light, gravity, ambient temperature) on elements of the circadian phase relationships during adaptation to microgravity and to fractional gravity loading during centrifugation will be assessed. Possible countermeasures (light intensity on photo period schedules) will be recommended.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Existing spaceflight data suggest changes in circadian period (in plants and animals) and phase relationships (in rodents and primates). The space station offers the unique opportunity to evaluate the influence of environmental synchronizers (e.g., light, gravity) on the known biological oscillating system and its subsystems.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 rodents, 6 squirrel monkeys.
 - B. Measurements/Samples:
Preflight: Heart rate, body temperature, locomotor activity, drinking frequency, feeding frequency, and sleep/wake. Gravity and light environment monitored and changed at programmed times.
In-Flight: Same as preflight.
Postflight: Same as preflight.
 - C. Sample Analysis:
In-flight: Sample analysis by automated microprocessor system.
Postflight: Same as in-flight.
 - D. Experiment Controls:
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Variable-g centrifuge and telemetry system.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 hr.
 - C. Experiment Site: LSRF: $\sqrt{\quad}$ Attached Payload: Platform:

METABOLIC REGULATION HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE						
		MR/SP A	MR/SP B	MR/SP C	MR/TM A	MR/TM B	MR/TM C	MR/TM D
Crew time (hr/90 day)		20	10	8	20	40	15	30
Item								
Biomedical recorder	8	1	1			1	1	1
Biotelemetry system	11	1	1	1	1	1	1	1
Cage cleaner	12	1	1	1	1	1	1	1
Cassette data recorder	6			1		1	1	1
Cell counter	1							
Cell culture apparatus	3							
Cell culture plate reader	2							
Centrifuge, laboratory	2							
Experimental control computer	7				1	1	1	1
Fluid handling kit	3					1		
Freezer (-20° C)	0							
Freezer (-70 °C)	3							
Freezer, cryo (-196° C)	1							
G control centrifuge (5')	1							
G control centrifuge (small)	1							
Gas chromatograph	2				1			
Glucose analyzer	1							
Guillotine	1							
Hand wash facility	15	1	1	1	1	1	1	1
Hematocrit centrifuge	2				1			
Hematology analyzer	2				1			
Implanted biotelemetry	11	1	1	1	1	1	1	1
Limb plethysmograph	1				1			
Mass measure, small	6				1	1	1	1
Mass spectrometer	5				1	1	1	1
Metabolic habitat	4				1	1	1	1
Micro computer system	9	1	1		1	1	1	1
Micro ultra centrifuge	1							
Multi-purpose work bench	15	1	1	1	1	1	1	1
Oscilloscope	1				1			
Performance evaluation facility	2		1					
Rhesus monkey food	2		1			1		
Rhesus monkey habitat	2		1			1		
Rhesus monkey water	2		1			1		
Rhesus restraint	1		1					
Rodent food	8					1		
Rodent metabolic module	2					1		
Rodent module	8					1		
Rodent restraint	4							
Rodent water	8					1		
Squirrel monkey acute restraint	3	1					1	1
Squirrel monkey food	9	1		1	1	1	1	1
Squirrel monkey module	9	1		1	1	1	1	1
Squirrel monkey water	9	1		1	1	1	1	1
Surgery/dissection kit	1							
Trash compactor	15	1	1	1	1	1	1	1
Variable-G centrifuge (13')	9	1			1	1	1	1
Video camera, recorder, supplies	1				1			
Whole body gradient layer calorimeter	4				1		1	1

METABOLIC REGULATION HARDWARE USE AND CREW TIME (BY EXPERIMENT) (CONCLUDED)

	EXPERIMENT CODE							
	MR/TM E	MR/CB A	MR/CB B	MR/CB C	MR/CB D	MR/CR A	MR/CR B	MR/CR C
Crew time (hr/90 day)	20	5	2	4	3	45	20	20
Item								
Biomedical recorder	1						1	1
Biotelemetry system	1					1	1	1
Cage cleaner	1	1				1	1	1
Cassette data recorder							1	1
Cell counter					1			
Cell culture apparatus			1	1	1			
Cell culture plate reader			1		1			
Centrifuge, laboratory	1			1				
Experimental control computer	1						1	1
Fluid handling kit		1	1					
Freezer (-20° C)								
Freezer (-70 °C)			1	1	1			
Freezer, cryo (-196° C)		1						
G control centrifuge (5')			1					
G control centrifuge (small)			1					
Gas chromatograph	1							
Glucose analyzer					1			
Guillotine		1						
Hand wash facility	1	1	1	1	1	1	1	1
Hematocrit centrifuge	1							
Hematology analyzer	1							
Implanted biotelemetry	1					1	1	1
Limb plethysmograph								
Mass measure, small	1					1		
Mass spectrometer	1							
Metabolic habitat								
Micro computer system	1					1		1
Micro ultra centrifuge				1				
Multi-purpose work bench	1	1	1	1	1	1	1	1
Oscilloscope								
Performance evaluation facility							1	
Rhesus monkey food								
Rhesus monkey habitat								
Rhesus monkey water								
Rhesus restraint								
Rodent food	1	1		1	1	1	1	1
Rodent metabolic module	1							
Rodent module	1	1		1	1	1	1	1
Rodent restraint	1	1		1	1			
Rodent water	1	1		1	1	1	1	1
Squirrel monkey acute restraint								
Squirrel monkey food						1	1	1
Squirrel monkey module						1	1	1
Squirrel monkey water						1	1	1
Surgery/dissection kit		1						
Trash compactor	1	1	1	1	1	1	1	1
Variable-G centrifuge (13')	1					1	1	1
Video camera, recorder, supplies								
Whole body gradient layer calorimeter	1							

J. MUSCLE STRUCTURE AND FUNCTION

RATIONALE FOR MUSCLE STRUCTURE AND FUNCTION EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR MUSCLE STRUCTURE AND FUNCTION

MUSCLE STRUCTURE AND FUNCTION EXPERIMENT TITLES

MUSCLE STRUCTURE AND FUNCTION EXPERIMENT DESCRIPTIONS

MUSCLE STRUCTURE AND FUNCTION EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

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Muscle Structure and Function

RATIONALE FOR MUSCLE STRUCTURE AND FUNCTION EXPERIMENTS ON SPACE STATION

Significant muscle changes have been demonstrated in animals during even short-term spaceflight. Muscle loss in response to microgravity appears to progress rapidly, especially in the antigravity muscles, and on longer-term manned flights has resulted in the use of daily exercise as a countermeasure. Development of a good human surrogate for these studies, such as rodents and/or nonhuman primates, will probably occur during short-term Spacelab flights prior to launch of the space station. The space station will offer the first opportunity to study mechanisms of muscle adaptation to spaceflight during long-term exposure.

It is recommended that the following sequence of approaches and levels of organization be conducted for these studies:

1. Characterize muscle changes in animal limbs on the histological and histochemical level.
2. Characterize muscle changes on the ultrastructural (electron microscopic) level, including myofibril, subcellular organelle, and neuromuscular junction effects.
3. Characterize muscle changes in contractile properties and electromyographic activity.
4. Characterize muscle changes on the biochemical level, including isozyme changes, regulation of protein biosynthesis and degradation, and general metabolic factors.
5. Characterize above parameters relative to rate of change with respect to time of exposure to microgravity and readaptation to 1 g.

PRIORITIZED SCIENCE OBJECTIVES FOR MUSCLE STRUCTURE AND FUNCTION

- MS/F-1 Histochemical analysis to determine rate of change of muscle fiber area, fiber type, glycolytic/oxidative enzyme concentrations of individual fibers, and degree of capillarity. (Red Book 5)
 Experiments: MS/F-A, E, F
- MS/F-2 Ultrastructural analysis of Z-line widths, Z-line registry, mitochondrial volumes, and neuromuscular junction morphology, cytoskeletal structure, and myotendinous/fibrochondral junctions. (Red Book 6)
 Experiments: MS/F-B, E
- MS/F-3 Determine by continuous electromyograph monitoring quantitative diminution in activity of atrophying muscle. (Red Book 7)
 Experiments: MS/F-C, E, F
- MS/F-4 1-g centrifuge countermeasure. (Red Book 8)
 Experiments: MS/F-A, B
- MS/F-5 Determine efficacy of tetanic muscle stimulation in preventing atrophy, and relate to bone atrophy. (Red Book 9)
 Experiments: MS/F-C, E
- MS/F-6 Determine how load/activity signal is transduced to biochemical agent(s) which regulate muscle protein synthesis (initiation/elongation). Quantify agent concentration in atrophying muscle. (Red Book 14)
 Experiments: MS/F-D, E
- MS/F-7 Assay for deficiency of paracrine/autocrine polypeptide growth factors, prostaglandins, and diacylglycerol and polyphosphoinositols as possible transduction agents. (Red Book 15)
 Experiments: MS/F-D, E
- MS/F-8 Determine changes in rates of myofibrillar protein degradation via lysosomal proteolysis, CA^{2+} activated proteases, ATP-dependent ubiquitin pathway, and cytosolic alkaline proteases. (Red Book 16)
 Experiments: MS/F-D, E
- MS/F-9 Catalog which skeletal muscles atrophy and determine their rates of involution. Measure by weight change and relate to 1 g \rightarrow 0 g transition. (Red Book 19)
 Experiments: MS/F-A, E, F
- MS/F-10 Determine which muscle proteins are preferentially and/or sequentially degraded in atrophying muscle, using immunochemical analysis and two-dimensional electrophoresis. (Red Book 20)
 Experiments: MS/F-D, E, F

MS/F-11 Determine whether muscle atrophy is endocrine-status-dependent (pituitary/target organ) by subjecting hypophysectomized rats to weightlessness. (Red Book 21)
Experiments: MS/F-A, B, E

MUSCLE STRUCTURE AND FUNCTION EXPERIMENT TITLES

Code	Title	Objective
MS/F-A	Muscle Loss in Rats in Microgravity (Histology - Histochemistry)	MS/F-1, 4, 9, 11
MS/F-B	Muscle Loss in Rats in Microgravity (Electron Microscopy/Ultrastructure)	MS/F-2, 4, 11
MS/F-C	Muscle Loss in Rats in Microgravity (Electron Microscopy/Contractile Properties)	MS/F-3, 5
MS/F-D	Muscle Loss in Rats in Microgravity (Biochemistry)	MS/F-6, 7, 8, 10
MS/F-E	Postnatal Development in Rats in Microgravity	MS/F-1-3; 5-11
MS/F-F	Muscle Loss in Rhesus Monkey Limbs Measured by CT Imaging During Microgravity	MS/F-1, 3, 9, 10

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE :**
 - A. Discipline/ Expt. Code: Muscle Structure and Function MS/F-A.
 - B. Science Objectives: MS/F-1, MS/F-4, MS/F-9, MS/F-11.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Muscle Loss in Rats in Microgravity (Histology- Histochemistry).
2. **PURPOSE/HYPOTHESIS:** Histochemical analysis to determine rate of change of fiber diameter, fiber type distribution; biochemical analysis to determine the concentrations of a complex (≈ 10) of glycolytic-oxidative enzymes in individual muscle fibers in rat skeletal muscles (soleus, gastronemius, etc.).
3. **PROGRAM RATIONALE/JUSTIFICATION:** Data will provide rates at which qualitative and quantitative atrophic changes occur in the process of adaptation to microgravity and relation to load-bearing and activity. When does muscle atrophy plateau?
4. **APPROACH:**
 - A. Number/Type Specimens: 24 adult male rats (300 - 350 grams): soleus, EDL, Ant. tibialis, and gastronemius muscles from each.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Dissect and clamp-freeze muscles. Autopsy after 0 g for 2, 4, 8, 12 wk (4 per group) = 16 rats. Same for 1 g.
Postflight: NA
 - C. Sample Analysis:
In-flight: None.
Postflight: Histological and histochemical analyses, single-fiber enzyme analyses (Lowry Single Fiber Method).
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
Ground-based: 24 adult male rats.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Clamp-freezer, freeze-drier, and animal centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 82.1 hr.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE :**
 - A. Discipline/ Expt. Code: Muscle Structure and Function MS/F-B.
 - B. Science Objectives: MS/F-2, MS/F-4, MS/F-11.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Muscle Loss in Rats in Microgravity (Electron Microscopy/Ultrastructure).
2. **PURPOSE/HYPOTHESIS:** Ultrastructural analyses of skeletal muscle atrophy (soleus, EDL, quadriceps) removed in-flight to characterize changes in myofibrils, mitochondrial morphology and distribution, and neuromuscular junction resulting from spaceflight.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Defines in morphological terms the characteristics of muscle atrophy induced by microgravity.
4. **APPROACH:**
 - A. Number/Type Specimens: 16 male adult rats. 4 groups (4 rats each) at 2, 4, 8, and 12 wk.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Perfuse, dissect, and fix muscles.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Post-flight: Electron microscope examination.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls, 4- and 12-wk exposure; 4 rats per group = 8 rats.
Ground-based: 24 ground-based controls as above.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): 1-g centrifuge, in vivo perfusion and fixation device; and implanted EMG telemetry/integrator/recorder.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 84 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

NOTE: Specimens for this study are not suitable for other experiments requiring fresh tissues because whole-body fixative perfusion is required.

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE :**
 - A. Discipline/ Expt. Code: Muscle Structure and Function MS/F-C.
 - B. Science Objectives: MS/F-3, MS/F-5.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Muscle Loss in Rats in Microgravity (Electron Microscopy/Contractile Properties).
2. **PURPOSE/HYPOTHESIS:** To determine rate of change in contractile properties of slow- and fast-twitch muscles of rat hind limb, and susceptibility to fatigue. Electromyograph analysis of activity patterns.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Test hypothesis that slow-twitch, tonically used soleus muscle slowly transforms to muscle showing more fast-twitch contractile properties with no change in susceptibility to fatigue.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 male adult rats. 6 groups (4 rats each) at 0, 1, 2, 4, 8, and 12 wk.
 - B. Measurements/Samples:
Preflight: Appropriate controls.
In-flight: In-flight baseline contractile properties measured in vivo under anaesthesia. (Contraction and relaxation times, isotonic and isometric, and maximum force generation.)
Monitor EMG activity of soleus and tibialis muscles 10 min of every 2 hr for above weeks before sacrifice in-flight.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls as above.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Square-wave electrostimulator, force transducers, and multichannel recorders. EMG electrodes and telemetry, receiver, integrator, and computer.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 60 hr.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE :**
 - A. Discipline/ Expt. Code: Muscle Structure and Function MS/F-D.
 - B. Science Objectives: MS/F-6, MS/F-7, MS/F-8, MS/F-10.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Muscle Loss in Rats in Microgravity (Biochemistry).
2. **PURPOSE/HYPOTHESIS:** Biochemical analyses of atrophying limb muscles of rat.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Investigate underlying biochemical changes and mechanisms of skeletal muscle atrophy.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 adult male rats (300 grams) per group—4 groups = 24 rats total. Soleus, EDL, Gastroc, and quadriceps.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Sample 6 rats at 1, 3 6, and 12 wk.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Hormone receptors: DNA, RNA, and protein. Specific enzyme analyses: alanine cycle, translational (RNA polymerases, protein initiation factors, capping factors); two-dimensional polyacrylamide gels; and myosin isozyme electrophoresis.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 24 rats on above schedule.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items):
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 65 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE :**
 - A. Discipline/ Expt. Code: Muscle Structure and Function MS/F-E.
 - B. Science Objectives: MS/F-1, 2, 3, 5, 6, 7, 8, 9, 10, 11.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Postnatal Development in Rats in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Ultrastructure, histochemistry, and biochemistry of F₁ generation of rats bred and reared in microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** To determine effect of weightlessness on muscle development in microgravity.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 (minimum) F₁ generation rats.
 - B. Measurements/Samples:
Preflight: None.
In-flight : Sacrifice and dissection. Sacrifice at 20, 30, 40, and 60 days of age (6 rats/group). Muscle biopsy for electron microscopy, histochemistry, and single-fiber samples. Preserve carcass for postflight analysis.
Postflight: Individual muscle weighing.
 - C. Sample Analysis:
In-flight: None.
Postflight analysis: EM, histochemistry, and single-fiber analysis (Lowry).
 - D. Experiment Controls:
In-flight: None.
Ground-based: 24 controls on above schedule.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Freeze-drier for muscle and clamp freezers for muscle.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 72 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE :**
 - A. Discipline/ Expt. Code: Muscle Structure and Function MS/F-F.
 - B. Science Objectives: MS/F-1, 3, 9, 10.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Muscle Loss in Rhesus Monkey Limbs Measured by CT Imaging During Microgravity.
2. **PURPOSE/HYPOTHESIS:** CT imaging of Rhesus monkey limb muscles to determine loss in cross-sectional area/volume.
3. **PROGRAM RATIONALE/JUSTIFICATION:** To determine rate of muscle loss in primates.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 adult male Rhesus monkeys, conditioned, and unrestrained.
 - B. Measurements/Samples:
Preflight: CT scan.
In-flight: CT scan of calf and thigh at 1, 2, 3, 4, 8, and 12 wk of flight.
Postflight: CT scan as for in-flight.
 - C. Sample Analysis:
In-flight : None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: 4 adult male Rhesus monkeys.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common item): High-precision CT scanner.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 46 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: √ Platform: √

NOTE: This experiment can be done in conjunction with experiment CH-G.

MUSCLE STRUCTURE HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE					
		MS A	MS B	MS C	MS D	MS E	MS F
Crew time (hr/90 day)		82	84	60	65	72	46
Item							
Animal perfusion kit	1		1				
Biomedical recorder	1		1				
Biotelemetry system	2		1	1			
Cage cleaner	6	1	1	1	1	1	1
CAT scanner	1						1
Experiment control computer	1			1			
Fixation kit	2	1	1				
Force transductor	1			1			
Freeze dryer	2	1				1	
Freezer (-20° C)	1				1		
Freezer (-70° C)	1	1					
Freezer, cryo (-196° C)	2	1				1	
G control centrifuge (8')	2	1	1				
Guillotine	2	1				1	
Hand wash facility	6	1	1	1	1	1	1
Implanted biotelemetry	2		1	1			
Mass measure, micro	2			1	1		
Mass measure, small	2		1		1		
Multi-purpose work bench	6	1	1	1	1	1	1
Muscle biopsy instruments	5	1	1	1	1	1	
Muscle electrostimulator	1			1			
Refrigerator (4° C)	1	1					
Rhesus monkey food	1						1
Rhesus monkey habitat	1						1
Rhesus monkey water	1						1
Rhesus restraint	1						1
Rodent food	5	1	1	1	1	1	
Rodent module	5	1	1	1	1	1	
Rodent water	5	1	1	1	1	1	
Trash compactor	6	1	1	1	1	1	1

K. NEUROSCIENCES

RATIONALE FOR NEUROSCIENCES EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR NEUROSCIENCES

NEUROSCIENCES EXPERIMENT TITLES

NEUROSCIENCES EXPERIMENT DESCRIPTIONS

**NEUROSCIENCES EXPERIMENT HARDWARE AND CREW-TIME
REQUIREMENTS**

RATIONALE FOR NEUROSCIENCES EXPERIMENTS ON SPACE STATION

The brain's evolution has been significantly shaped by the fact that humans exist in an ever-present, constant-magnitude gravitational field. Just as other physiological systems evolved to solve the problems of living under specific terrestrial conditions, the brain provides biological controls enabling adaptive functioning in Earth's gravitational field. An obvious example is the brain "programs" which enable the control of movements and positioning of body parts in space. These programs sense the position of the body's parts with respect to each other and to the gravitational field. They move the limbs and the head against gravity, and when the pull of gravity is removed, they are no longer appropriate and must be modified to compensate.

What are the consequences of long-term removal from Earth's gravity on the way in which the brain carries out its basic functions, on its control of somatic and visceral muscles, on its ability to program movements accurately, on the accuracy of sensory perception, or on the likelihood of debilitating malfunctions? Are changes marked, nonexistent, or somewhere in between? Are changes irreversible, or can they be reversed either with or without intervention? It is imperative to find the answers. Prior to spaceflight, there was neither a way to manipulate this important biological variable, nor was there so imperative a need to study its effects systematically. The degree to which neurophysiological systems are able to adapt and the reversibility of that adaptation process on return to Earth are central problems which require answers as NASA works toward its goal of long-duration manned spaceflight. Also, the determination of the exact mechanism(s) underlying long-term changes in neurophysiological systems after removal from Earth's gravity is a problem of general interest for neuroscience in the 1990s and beyond.

A logical starting point for early investigations is with studies of the effects of long-term exposure to microgravity on the many functions the vestibular labyrinth controls, because it is already known that 1) vestibular functions depend on gravity for normal function, and 2) vestibular system performance is altered during spaceflight.

Other physiological systems controlled by the brain may also be affected by the removal of the constant influence of gravity in as yet undetermined ways. For example, the brain 1) provides a continual background drive to the skeletal and visceral muscle regulating its baseline contractility, 2) controls the movements of muscles which control the orientation of head and limbs with respect to the body and to gravity, and 3) plays an important role in regulating glandular control.

The following representative experiments using animal models address questions about the ability of the brain to adapt to microgravity, and the mechanisms involved in this adaptation. These experiments are designed to support and supplement experiments investigating similar questions in humans. The use of experimental animals permits the testing of hypotheses that would be difficult or impossible to test in humans. For example, the efficacy of experimental drugs can be tested, more accurate measures, which frequently require invasive techniques, can be made, tissue samples can be harvested following experiments, etc.

The experimental package which follows consists of a few principal groups of experiments designed to determine the effects of long-term exposure to microgravity and the effects of fractional levels of artificial gravity produced by centrifugation on 1) the anatomy and physiology of neurons and reflexes (e. g., vestibular or somato-motor) which are normally dependent on Earth's gravity, 2) susceptibility to and severity of motion sickness induced by provocative stimuli, 3) the capacity and time course of readaptation of gravity-dependent parts of the nervous system to 1 g postflight, 4) development of nervous system structure and function normally dependent on gravity and, 5) effects of microgravity exposure on basic nervous system functions (e.g., metabolic and transmitter).

PRIORITIZED SCIENCE OBJECTIVES FOR NEUROSCIENCES

- NS-1 Determine time course of structural and neurosensory changes underlying adaptation to 0 g. (Red Book-1)
Experiments: NS-A, C, D, F, G, I, J, K, L, N, P, R, T, V, W, X, AA, CC
- NS-2 How can adaptation to 0 g be facilitated (e.g., by fractional gravity, pharmacology, biobehavioral, or mechanical training)? (Red Book-2)
Experiments: NS-B, E, H, M, O, Q, S, U, W, CC
- NS-3 What are the necessary conditions for provoking space motion sickness early in flight and after prolonged periods in space? (Red Book-3)
Experiments: TBD
- NS-4 Determine time course of structural and neurosensory changes underlying readaptation to 1 g (e.g., determine cause(s) of postflight ataxia/motion sickness). (Red Book-4)
Experiments: NS-C, F, I, J, K, L, M, O, P, R
- NS-5 How can deleterious effects of exposure to 0 g be prevented (e.g., fractional gravity? Pharmacology?) (Red Book-5)
Experiments: NS-B, E, H, K, M, O, Q, V, Y, W, AA
- NS-6 How can readaptation to 1 g be facilitated (e.g., by gravity exposure prior to return, Pharmacology, etc.) (Red Book-6)
Experiments: NS-K, M, O, U
- NS-7 What levels of gravity are required to maintain a normally functioning vestibular system? (Red Book-8)
Experiments: NS-B, E, H, K, M, O, Q, V, W, Y, AA
- NS-8 Are there critical periods in the development of the vestibular system (i.e., are there deficits if the system develops in 0 g?) (Red Book-9)
Experiments: NS-T, V, X, Y, Z, AA
- NS-9 How is the central nervous system metabolism influenced by microgravity and fractional gravity? (Red Book-Basic Animal Research/Gen-3)
Experiments: NS-N, DD
- NS-10 How does the central nervous system neurotransmitter system respond to microgravity and fractional gravity? (Red Book-Basic Animal Research/Gen - 3)
Experiments: NS-N, EE

NEUROSCIENCES EXPERIMENT TITLES

Code	Title	Objective
NS-A	Structural Changes in the Rat's Labyrinth in Microgravity	NS-1
NS-B	Prevention of Structural Changes in the Rat's Labyrinth in Microgravity by Application of Fractional Gravity Loads	NS-2,6,7
NS-C	Structural Changes in Vestibular Labyrinth During Readaptation to Earth's Gravity	NS-1,4
NS-D	The Nature and Potential Consequences of Microgravity-Related Structural Changes in Pathways Mediating Vestibular Reflexes	NS-1
NS-E	Effectiveness of Fractional Gravity Loading in Countering Microgravity-Related Structural Changes in Pathways Mediating Vestibular Reflexes	NS-2,6,7
NS-F	Structural Changes in Vestibular Connections During Readaptation to Earth's Gravity	NS-1,4
NS-G	Effect of Adaptation to Microgravity on Vestibular Nerve Activity Normally Dependent on Earth's Gravity	NS-1
NS-H	The Effect of Fractional Gravity Loading on Vestibular Nerve Neurons During Adaptation to Microgravity	NS-2,6,7
NS-I	Recovery of Function of Gravity-Sensitive Vestibular Nerve Neurons in Earth's Gravity After Exposure to Microgravity	NS-1,4
NS-J	Adaptation to Microgravity by Gravity-Sensitive Central Vestibular Neurons Controlling Reflexes	NS-1,4
NS-K	Effect of Fractional Gravity on the Adaptation of Gravity-Dependent Central Vestibular Neurons to Microgravity	NS-1,4,5,6,7
NS-L	Changes in Gravity-Dependent Vestibular Reflexes During Microgravity: Readaptation of Those Reflexes to Earth's Gravity	NS-1,4
NS-M	Effect of Partial Loading on Vestibular Reflexes During Adaptation to Fractional Gravity and Readaptation to Earth's Gravity	NS-2,4,5,6,7

Neurosciences

NS-N	The Effects of Adaptation to Microgravity on Otolith Functions as Measured Using Ocular Counterrolling	NS-1,9,10
NS-O	Effect of Fractional Gravity on Vertical and Counterrolling Eye Movements	NS-2,4,5,6,7
NS-P	Effect of Adaptation to Microgravity on Optokinetic Function; Recovery of Optokinetic Response During Readaptation to Earth's Gravity	NS-1,4
NS-Q	Effect of Fractional Gravity on Visual-Vestibular Interactions Indicated by Optokinetic Nystagmus	NS-2,6,7
NS-R	Characteristics of the Horizontal Vestibulo-Ocular Reflex During Passive Body Oscillation in Microgravity and During Readaptation to Earth's Gravity	NS-1,4
NS-S	Effect of Chronological Age on Ability to Adapt to Microgravity	NS-2
NS-T	Effect of Adaptation to Microgravity on Vestibular System Changes Associated with Aging	NS-1,8
NS-U	Effect of 1-g Centrifugation on Susceptibility to Space Motion Sickness in Squirrel Monkeys	NS-2,5
NS-V	Production of Space Motion Sickness by Provocative Vestibular Stimuli During Adaptation to Microgravity and Fractional Gravity	NS-1,6,7,8
NS-W	Effects of Provocative (Motion Sickness-Inducing) Stimuli on Vestibular Neurons and Reflexes During Adaptation to Microgravity	NS-1,2,6,7
NS-X	Effect of Microgravity Exposure on the Labyrinth's Anatomic Development and Neural Connections	NS-1,8
NS-Y	Effect of Fractional Gravity Loads on the Labyrinth's Anatomic Development and Neural Connections	NS-7,8
NS-Z	Effects of "Gravity Deprivation" on Nervous System Structures and Functions that Depend on Earth's Gravity for Normal Development	NS-8
NS-AA	Does Fractional Gravity Loading Reduce Microgravity-Related Developmental Anomalies of Nervous System Structures and Functions?	NS-1,6,7,8
NS-BB	Effects of Long-Duration Exposure to Microgravity and Fractional Gravity on Spinal Cord Motorneurons, Peripheral Nerve, and Motor Endplates of Anti-Gravity Muscles	MS/F-2

Neurosciences

NS-CC	Effects of Microgravity on Gravity Receptor Development Across Generations: Effects of Fractional Gravity Loads on Development Across Generations	NS-1,2
NS-DD	Central Nervous System Metabolism During Spaceflight	NS-9
NS-EE	Neurotransmitter Receptor Changes in Altered Gravity	NS-10

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-A.
 - B. Science Objectives: NS-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Structural Changes in the Rat's Labyrinth in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine and describe structural alterations which occur in the vestibular labyrinth during exposure to microgravity, and to identify their potential consequences to normal physiological function on long-duration spaceflights.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The existence of structural changes in the vestibular labyrinth and any associated physiological or performance decrements is an essential question to answer for long-duration spaceflight.
4. **APPROACH:**
 - A. Number/Type Specimens: 100 adult rats (50 experimental, 50 1-g controls, experiment duration 360 days).
 - B. Measurements/Samples:
Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility or equivalent.
In-flight: Vital signs daily, sacrifice, dissection, and fixation of 10 experimental and 10 control animals at 90-day intervals.
Postflight: Sacrifice, dissection, and fixation of tissues.
 - C. Sample Analysis:
In-flight: None.
Postflight: Histological processing, and light and electron microscopy.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Centrifuge capable of maintaining 50 adult rats at 1-g in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/rat/90 day} = 0.5 \times 20 = 10 \text{ hr}.$
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-B.
 - B. Science Objectives: NS-2, NS-6, NS-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Prevention of Structural Changes in the Rat's Labyrinth in Microgravity by Application of Fractional Gravity Loads.
2. **PURPOSE/HYPOTHESIS:** To determine the degree to which flight-related structural (anatomic) alterations in the vestibular labyrinth can be mitigated by fractional gravitational loads provided by an on-board centrifuge.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Evaluate the efficacy of in-flight centrifugation in the prevention of structural (anatomic) alterations in the vestibular labyrinth.
4. **APPROACH:**
 - A. Number/Type Specimens: 200 adult rats (100 experimental, half held at 0.33, and half at 0.66 g; 50 0-g controls; 50 1-g controls).
 - B. Measurements/Samples:

Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility or equivalent.

In-flight: Vital signs daily; sacrifice, dissection, and fixation of 10 experimental animals, and 10 from each of the two control groups at 90-day intervals.

Postflight: Sacrifice, dissection, and fixation of tissues; centrifuge history in-flight.
 - C. Sample Analysis:

In-flight: None.

Postflight: Histological processing, light and electron microscopy.
 - D. Experiment Controls:

In-flight: Controls are two groups of animals, one held at 1-g and a second at ambient microgravity, and sacrificed at 90-day intervals (i.e., the animals from experiment NS-A).
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board specimen centrifuge for providing altered gravitational force to specimens in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/rat/90 day} = 0.5 \text{ hr} \times 30 = 15 \text{ hr}.$
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-C.
 - B. Science Objectives: NS-1, NS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Structural Changes in Vestibular Labyrinth During Readaptation to Earth's Gravity.
2. **PURPOSE/HYPOTHESIS:** To determine and describe structural alterations seen in the vestibular labyrinth immediately postflight and during the process of readaptation to Earth's gravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is essential to know whether structural alterations seen postflight are permanent or whether anatomic changes return to normal after periods of reexposure to Earth's gravity. These studies will assess the mechanism and significance of the changes on long-term recoverability of labyrinth structures.
4. **APPROACH:**
 - A. Number/Type Specimens: 50 adult rats.
 - B. Measurements/Samples:
Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility.
In-flight: Monitor health status daily.
Postflight: Sacrifice, dissect, fix tissue on postflight days 1, 10, 20, 40, 90 (i.e., 10 rats in each postflight sample group).
 - C. Sample Analysis:
In-flight: None.
Postflight: Light and electron microscopy of histologically preserved vestibular neuroepithelium and related structures.
 - D. Experiment Controls:
In-flight: TBD.
Ground-based: TBD.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-D.
 - B. Science Objectives: NS-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): The Nature and Potential Consequences of Microgravity-Related Structural Changes in Central Pathways Mediating Vestibular Reflexes.
2. **PURPOSE/HYPOTHESIS:** To determine the nature and potential consequences of structural alterations in connectivity of central reflex pathways resulting from altered sensory inputs in microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** During the process of readaptation, reprogramming of sensorimotor interactions occurs. It is important to determine the structural substrates of those functional changes.
4. **APPROACH:**
 - A. Number/Type Specimens: 70 adult rats.
 - B. Measurements/Samples:
Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility or equivalent.
In-flight: Vital signs daily; sacrifice, dissection, and fixation of 5 experimental and 5 control specimens on days 1, 3, 10, 20, 40, and 90, with 5 experimental and 5 control animals returned to ground at end of 90 days.
Postflight: TBD.
 - C. Sample Analysis:
In-flight: None.
Postflight: Light and electron microscopy, immunocytochemistry, etc., depending on the exact experiment being performed.
 - D. Experiment Controls:
In-flight: 35 specimens in home cages on 1-g centrifuge.
Ground-based: TBD.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Centrifuge capable of maintaining 35 adult rats at 1-g in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/rat} \times 6/90 \text{ day} = 3 \text{ hr} \times 10 = 30 \text{ hr} + 2 \text{ hrs for return.}$
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-E.
 - B. Science Objectives: NS-2, NS-6, NS-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effectiveness of Fractional Gravity Loading in Countering Microgravity-Related Structural Changes in Pathways Mediating Vestibular Reflexes.
2. **PURPOSE/HYPOTHESIS:** To determine the extent to which anatomic changes seen in vestibular pathways (Expt NS-D) can be offset by use of partial gravity loading provided by an on-board centrifuge.
3. **PROGRAM RATIONALE/JUSTIFICATION:** If there are changes in the neural substrate of vestibular function, either anatomic or transmitter-related, it will be important to know whether the changes can be prevented or reduced by partial gravitational exposure, and if so, to define the minimum level necessary.
4. **APPROACH:**
 - A. Number/Type Specimens: 90 adult rats (30 at 1-g, 30 at 0.5 g, and 30 at 0.25 g).
 - B. Measurements/Samples:
Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility or equivalent.
In-flight: Vital signs daily; sacrifice, dissection, and fixation of 5 specimens from each group on days 1, 3, 10, 20, 40, and 90. Light and electron microscopy.
Postflight: N/A.
 - C. Sample Analysis:
In-flight: Immunocytochemistry, etc., as dictated by experiment needs.
Postflight: None.
 - D. Experiment Controls:
In-flight: 1-g controls.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board centrifuge for providing partial gravitational force to specimens in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/rat} \times 6/90 \text{ day} = 3 \text{ hr} \times 15 = 45 \text{ hr}.$
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-F.
 - B. Science Objectives: NS-1, NS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Structural Changes in Vestibular Connections During Readaptation to Earth's Gravity.
2. **PURPOSE/HYPOTHESIS:** To determine which, if any, changes to the vestibular neural substrate return to normal after return to Earth's gravity after long-term exposure to microgravity, and the time course of the recovery process.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is important to determine whether structural changes resulting from long-duration exposure to microgravity are permanent or temporary before exposing humans to longer periods in space.
4. **APPROACH:**
 - A. Number/Type Specimens: 90 adult rats (30 to be returned to Earth following 90 days, 30 following 180 days, and 30 following 360 days exposure to microgravity).
 - B. Measurements/Samples:
Preflight: Vestibular function testing in Ames Vestibular Research Facility or equivalent.
In-flight: Vital signs daily.
Postflight: Light and electron microscopy.
 - C. Sample Analysis:
In-flight: None.
Postflight: Immunocytochemistry, etc., depending on the objectives of particular experiments.
 - D. Experiment Controls:
In-flight: None.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-G.
 - B. Science Objectives: NS-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Adaptation to Microgravity on Vestibular Nerve Activity Normally Dependent on Earth's Gravity.
2. **PURPOSE/HYPOTHESIS:** To identify and characterize vestibular nerve activity changes during adaptation to microgravity, to determine whether labyrinthine physiology is normal in microgravity, and to identify the consequences of observed changes on normal physiological function.
3. **PROGRAM RATIONALE/JUSTIFICATION:** There may be changes in vestibular transduction processes due to body-fluid shifts, disturbances in electrolyte balance, or biochemical alterations of otolith organs caused by their unloading in microgravity; these changes may not be detected anatomically. Therefore it is important to investigate whether there are functional alterations during prolonged exposure to microgravity, as revealed by vestibular nerve activity. (Fabricant report, pp. 77, 78).
4. **APPROACH:**
 - A. Number/Type Specimens: Probably two animals at any one time. Various species depending on the size of centrifuge available and the particulars of the experiment.
 - B. Measurements/Samples:
Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility, daily recording sessions to establish baseline recording properties.
In-flight : Vital signs daily, single-cell recording sessions daily.
Postflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility.
 - C. Sample Analysis:
In-flight: Computer analysis of neural data, nature TBD by stimulus capabilities.
Postflight: Computer analysis of neural data, nature TBD by stimulus capabilities, sacrifice for histological examination TBD by nature of experiment.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board specimen centrifuge for providing partial gravitational force to specimens in home cages. Device for delivering controlled vestibular test stimuli.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-H.
 - B. Science Objectives: NS-2, NS-6, NS-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): The Effect of Fractional Gravity Loading on Vestibular Nerve Neurons During Adaptation to Microgravity.
2. **PURPOSE/HYPOTHESIS:** To characterize the response of vestibular nerve neurons during adaptation to background levels of fractional gravitational acceleration provided by an on-board centrifuge.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The protection conferred by fractional gravity loading against changes in vestibular nerve neuron responses during microgravity should be evaluated.
4. **APPROACH:**
 - A. Number/Type Specimens: Probably two experimental animals at any one time. Various species depending on size of centrifuge available and the particulars of the experiment.
 - B. Measurements/Samples:
Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility, daily recording sessions to establish baseline recording properties.
In-flight: Vital signs daily, single-cell recording sessions daily.
Postflight: Vestibular function testing (protocols TBD).
 - C. Sample Analysis:
In-flight: Computer analysis of neural data, nature TBD by stimulus capabilities.
Postflight: Computer analysis of neural data, nature TBD by stimulus capabilities, sacrifice for histological recovery TBD by nature of experiment.
 - D. Experiment Controls:
In-flight: Two specimens on 1-g centrifuge.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board specimen centrifuge for providing partial gravitational force to specimens in home cages and a device for delivering controlled vestibular test stimuli.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-I.
 - B. Science Objectives: NS-1, NS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Recovery of Function of Gravity-Sensitive Vestibular Nerve Neurons in Earth's Gravity After Exposure to Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine the course of recovery of vestibular nerve function during readaptation to Earth's gravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is necessary to determine how normal function is reestablished so that readaptation may be facilitated.
4. **APPROACH:**
 - A. Number/Type Specimens: Two specimens—squirrel monkey is species of choice, although others may be acceptable.
 - B. Measurements/Samples:
Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility.
In-flight: Vital signs daily.
Postflight: Recording sessions on days 1, 3, 10, 20, 40, ... until normal function returns.
 - C. Sample Analysis:
In-flight: None.
Postflight: Computer analysis of neural data, nature TBD by stimulus capabilities, sacrifice for histological recovery TBD by nature of experiment.
 - D. Experiment Controls:
In-flight: None.
Postflight: Two specimens exposed to the same stimulus and recording conditions as the experimental specimens.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-J.
 - B. Science Objectives: NS-1, NS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Adaptation to Microgravity by Gravity-Sensitive Central Vestibular Neurons Controlling Reflexes.
2. **PURPOSE/HYPOTHESIS:** To identify and characterize changes in the physiological response properties of central neural pathways controlling vestibular system reflexes during exposure to microgravity and during readaptation to Earth's gravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Peripheral vestibular physiology is undoubtedly altered by exposure to microgravity. It seems reasonable to postulate that such alterations in sensory inputs necessitate adaptive changes in reflex control mechanisms which integrate vestibular, visual, proprioceptive and somatosensory receptors during motion. There is a need for research to understand where and how the central nervous system processes such information.
4. **APPROACH:**
 - A. Number/Type Specimens: 2 squirrel monkeys.
 - B. Measurements/Samples:

Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility, daily recording sessions to establish baseline properties of gravity-sensitive single cells and reflexes.

In-flight: Vital signs daily, single-cell and reflex testing daily.

Post-flight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility, daily recording sessions for gravity-sensitive single cells and reflexes.
 - C. Sample Analysis:

In-flight: Computer analysis of neural data, nature TBD by stimulus capabilities.

Postflight: Computer analysis of neural data, nature TBD by stimulus capabilities, sacrifice for histological examination TBD by nature of experiment.
 - D. Experiment Controls:

In-flight: TBD depending on exact details of experiment.

Ground-based: TBD.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular stimulation device.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-K.
 - B. Science Objectives: NS-1, NS-4, NS-5, NS-6, NS-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Fractional Gravity on the Adaptation of Gravity-Dependent Central Vestibular Neurons to Microgravity.
2. **PURPOSE/HYPOTHESIS:** To characterize the way in which neurons of central neural pathways respond during adaptation to background levels of fractional gravity acceleration provided by an on-board centrifuge.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Processes of adaptation at the cellular level in the vestibular nuclei, if it occurs there, or in the vestibular neuroepithelium, are essentially unknown. Similarly, the cerebellum is thought to have a prominent role in habituation, but where and how it takes place is not clear.
4. **APPROACH:**
 - A. Number/Type Specimens: 8 squirrel monkeys (2 at 0-g, 2 at 0.25 g, 2 at 0.5 g, and 2 at 1 g).
 - B. Measurements/Samples:

Preflight: Vestibular function testing (protocols TBD) in Ames Vestibular Research Facility, daily recording sessions to establish baseline properties of gravity-sensitive single cells and reflexes.

In-flight: Vital signs daily, single-cell and reflex testing daily.

Postflight: TBD.
 - C. Sample Analysis:

In-flight: Computer analysis of neural data, nature TBD by stimulus capabilities.

Postflight: Computer analysis of neural data, nature TBD by stimulus capabilities, sacrifice for histological examination TBD by nature of experiment.
 - D. Experiment Controls:

In-flight: The two 0-g specimens are the controls.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular testing apparatus; on-board centrifuge capable of maintaining squirrel monkeys at 0.25, 0.5, and 1 g.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-L.
 - B. Science Objectives: NS-1, NS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Changes in Gravity-Dependent Vestibular Reflexes During Microgravity: Readaptation of Those Reflexes to Earth's Gravity.
2. **PURPOSE/HYPOTHESIS:** To determine the exact behavioral status of vestibular (semicircular canal and otolith) function as expressed in vestibulo-ocular, vestibulo-collic, and vestibulo-spinal reflexes during long-term exposure to 0-g, and during readaptation to Earth's gravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is important to determine the extent to which the adaptations to weightlessness are similar in humans and monkeys if an animal model or models are to be developed. Animal models will be important because the changes observed during weightlessness should provide clues as to which neuronal systems would be most interesting to explore with single-unit techniques and may suggest hypotheses for countermeasures.
4. **APPROACH:**
 - A. Number/Type Specimens: 2 squirrel monkeys.
 - B. Measurements/Samples:
Preflight: Baseline measurement of battery of gravity-dependent reflex functions (protocols TBD) in Ames Vestibular Research Facility or equivalent.
In-flight: Daily vital signs, battery of gravity-dependent vestibular reflex tests on days 1, 3, 5, 10, 20, 40, and 90.
Postflight: Vestibular function testing using the same battery of vestibular reflex tests.
 - C. Sample Analysis:
In-flight: Preliminary reflex analysis.
Postflight: Complete analysis.
 - D. Experiment Controls:
In-flight: None.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular testing apparatus, perhaps like the Ames Vestibular Research Facility centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-M.
 - B. Science Objectives: NS-2, NS-4, NS-5, NS-6, NS-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Partial Loading on Vestibular Reflexes During Adaptation to Fractional Gravity, and Readaptation to Earth's Gravity
2. **PURPOSE/HYPOTHESIS:** To characterize the vestibulo-ocular, vestibulo-collic, and vestibulo-spinal reflexes during adaptation to background levels of fractional gravitational accelerations provided by an on-board centrifuge, and during readaptation to Earth's gravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** If there are peripheral abnormalities in vestibular reflex function, what steps can be taken to prevent or ameliorate them? The protection offered by fractional gravity load, such as provided by an on-board animal centrifuge should be explored (Fabricant, p. 78).
4. **APPROACH:**
 - A. Number/Type Specimens: 8 squirrel monkeys (2 at 0-g, 2 at 0.25 g, 2 at 0.5 g, and 2 at 1 g).
 - B. Measurements/Samples:
Preflight: Vestibular function testing (protocols TBD) and daily recording sessions in the Ames Vestibular Research Facility to establish baseline properties of gravity-sensitive single cells and reflexes.
In-flight: Vital signs daily, single-cell and reflex testing daily.
Postflight: Daily vestibular function testing and single-cell and reflex testing.
 - C. Sample Analysis:
In-flight: Computer analysis of neural data, and nature TBD by stimulus capabilities.
Postflight: Computer analysis of neural data, nature TBD by stimulus capabilities, and sacrifice for histological examination TBD by nature of experiment.
 - D. Experiment Controls: The two 0-g specimens are the controls.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular testing apparatus, perhaps like the Ames Vestibular Research Facility centrifuge; on-board centrifuge capable of maintaining squirrel monkeys at 0.25 g, 0.5 g, and 1.g.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-N.
 - B. Science Objectives: NS-1, NS-9, NS-10.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): The Effects of Adaptation to Microgravity on Otolith Functions as Measured Using Ocular Counterrolling.
2. **PURPOSE/HYPOTHESIS:** To determine response characteristics of static and dynamic ocular counterrolling with voluntary lateral head movement or passive oscillations about a roll axis and to determine characteristics of vertical eye movements elicited by pitching head movements.
3. **PROGRAM RATIONALE/JUSTIFICATION:** These experiments would supplement human experiments suggested by the Fabricant report (p. 86) concerning whether counterrolling is present in microgravity and whether its gain is increased over time. Using ocular counterrolling, the influence of altered otolith input and its adaptation can be determined.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 squirrel monkeys (2 experimental animals at ambient gravity level, 2 controls at 1 g).
 - B. Measurements/Samples:

Preflight: Characterization of ocular counterrolling and vertical eye movements in the Ames Vestibular Research Facility.

In-flight: Daily monitoring of vital signs, characterization of ocular counterrolling and vertical eye movements on days 1, 2, 4, 8, 20, 40, 75, and 90.

Postflight: Characterization of both counterrolling and vertical eye movements until recovery is complete.
 - C. Sample Analysis:

In-flight: Computer analysis of reflex results.

Postflight: Same as in-flight.
 - D. Experiment Controls:

In-flight: 2 specimens on 1-g centrifuge.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular testing apparatus, perhaps similar to the Ames Vestibular Research Facility centrifuge; on-board centrifuge capable of maintaining two squirrel monkeys at 1-g in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-O.
 - B. Science Objectives: NS-2, NS-4, NS-5, NS-6, NS-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Fractional Gravity on Vertical and Counterrolling Eye Movements.
2. **PURPOSE/HYPOTHESIS:** Using an on-board centrifuge, determine the level of fractional gravity loading which restores normal vertical and counterrolling reflexive eye movements.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Otolith function is undoubtedly affected when an organism is removed from Earth's gravity field. Otolith-related eye movements are therefore probably also affected by adaptation to microgravity. It is therefore important to know whether and how exposure to fractional gravity levels will ameliorate the effects of exposure to microgravity in otolith-related oculomotor reflexes.
4. **APPROACH:**
 - A. Number/Type Specimens: 8 squirrel monkeys (2 at 0 g, 2 at 0.25 g, 2 at 0.5 g, and 2 at 1 g).
 - B. Measurements/Samples:
Preflight: Characterization of ocular counterrolling and vertical eye movements in the Ames Vestibular Research Facility.
In-flight: Daily monitoring of vital signs, characterization of ocular counterrolling and vertical eye movements on days 1, 2, 4, 8, 20, 40, 75, and 90.
Postflight: Characterization of counterrolling and vertical eye movements until recovery is complete.
 - C. Sample Analysis:
In-flight: Computer analysis of reflex results.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: 2 specimens on 1-g centrifuge.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular testing apparatus, perhaps similar to the Ames Vestibular Research Facility centrifuge and on-board centrifuge capable of maintaining squirrel monkeys at 1-g in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-P.
 - B. Science Objectives: NS-1, NS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Adaptation to Microgravity on Optokinetic Function: Recovery of Optokinetic Response During Readaptation to Earths' Gravity.
2. **PURPOSE/HYPOTHESIS:** To determine the effect of adaptation to microgravity on optokinetic function (slow component of optokinetic nystagmus and after-nystagmus) and the course of recovery after return to Earth gravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Optokinetic function, including the slow component of optokinetic nystagmus and optokinetic after-nystagmus are intimately related to the vestibular mechanisms of self-motion perception, and these experiments will determine the nature of these mechanisms in adaptation to microgravity (Fabricant, p. 79).
4. **APPROACH:**
 - A. Number/Type Specimens: 4 squirrel monkeys.
 - B. Measurements/Samples:
Preflight: Characterization of optokinetic eye movements in the Ames Vestibular Research Facility.
In-flight: Daily monitoring of vital signs, characterization of optokinetic eye movements on days 1, 3, 5, 10, 20, 40, 75, and 90.
Postflight: Characterization of optokinetic eye movements until recovery is complete.
 - C. Sample Analysis:
In-flight: Computer analysis of reflex results.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: 2 specimens on 1-g centrifuge.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Optokinetic test device.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-Q.
 - B. Science Objectives: NS-2, NS-6, NS-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Fractional Gravity on Visual-Vestibular Interactions as Indicated by Optokinetic Nystagmus.
2. **PURPOSE/HYPOTHESIS:** To determine whether the effects of microgravity on visual-vestibular interactions as revealed by optokinetic nystagmus can be mitigated by exposure to partial gravitational fields using an on-board centrifuge.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Optokinetic function, including the slow component of optokinetic nystagmus and optokinetic after-nystagmus are intimately related to the vestibular mechanisms of self-motion perception, and these experiments will determine the nature of these mechanisms in adaptation to microgravity (Fabricant, p. 79).
4. **APPROACH:**
 - A. Number/Type Specimens: 8 squirrel monkeys (2 at 0 g, 2 at 0.25 g, 2 at 0.5 g, and 2 at 1 g).
 - B. Measurements/Samples:
Preflight: Characterization of optokinetic eye movements in the Ames Vestibular Research Facility.
In-flight: Daily monitoring of vital signs, characterization of optokinetic eye movements on days 1, 3, 5, 10, 20, 40, 75, and 90.
Postflight: Characterization of optokinetic eye movements until recovery is complete.
 - C. Sample Analysis:
In-flight: Computer analysis of reflex results.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: 2 specimens on 1-g centrifuge.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Optokinetic test device; variable-g centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-R.
 - B. Science Objectives: NS-1, NS-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Characteristics of the Horizontal Vestibulo-Ocular Reflex During Passive Body Oscillation in Microgravity and During Readaptation to Earth's Gravity.
2. **PURPOSE/HYPOTHESIS:** To determine the characteristics of the horizontal vestibulo-ocular reflex during passive body oscillation during and after long-term exposure to microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** These experiments would supplement human experiments suggested by the Fabricant report (p. 86). In addition, these experiments will examine whether the canals are gravity-dependent, will describe the time-course of the adaptation, and will track the recovery of function during readaptation to Earth gravity.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 squirrel monkeys.
 - B. Measurements/Samples:
Preflight: Characterization of horizontal vestibulo-ocular reflex (HVOR) in the Ames Vestibular Research Facility.
In-flight: Daily monitoring of vital signs, characterization of HVOR on days 1, 3, 5, 10, 20, 40, 75, and 90.
Postflight: Characterization of HVOR until recovery is complete.
 - C. Sample Analysis:
In-flight: Computer analysis of HVOR results.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: 2 specimens maintained on 1-g centrifuge.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular testing apparatus; on-board centrifuge for 1 g.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-S.
 - B. Science Objectives: NS-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Chronological Age on Ability to Adapt to Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of chronological age on ability to adapt to microgravity, as indicated by adaptation of vestibular reflexes.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The rate at which adaptation occurs may be a function of the age experience of the organism. For long-duration manned flights, it is important to know how vestibular as well as other parts of the nervous system adapt to microgravity and readapt to Earth's gravity in older versus younger organisms.
4. **APPROACH:**
 - A. Number/Type Specimens: 100 rats of various ages.
 - B. Measurements/Samples:
Preflight: Background, baseline characterization of vestibulo-ocular, vestibulo-collic, and postural reflexes using the Ames Vestibular Research Facility or equivalent.
In-flight: Vital signs daily, characterization of vestibulo-ocular, vestibulo-collic, and postural reflexes on days 1, 2, 4, 8, 12, 20, 40, and 90.
Postflight: Measurements of recovery of same reflex function.
 - C. Sample Analysis:
In-flight: Computer analysis of reflex results.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: Matched group of control animals held at 1-g in an on-board centrifuge, and tested in same way as experimental animals.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular testing apparatus to generate stimuli for reflex testing. On-board centrifuge for holding rats at 1-g in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-T.
 - B. Science Objectives: NS-1, NS-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Adaptation to Microgravity on Vestibular System Changes Associated with Aging.
2. **PURPOSE/HYPOTHESIS:** To determine the effect of microgravity on structural and functional changes in the vestibular system which are normally associated with aging.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The vestibular system receptors and pathways change as humans and animals age. For example, receptor cell populations decrease in number and change morphologically as a function of age. The mechanisms underlying such changes are not understood. It will be important to understand whether exposure to microgravity for prolonged periods will affect the aging of the vestibular system.
4. **APPROACH:**
 - A. Number/Type Specimens: 100 rats of various ages. (50 experimental animals at ambient microgravity level; 50 control animals held at 1 g.)
 - B. Measurements/Samples:
 - Preflight: Vestibular reflex testing to assure normality of sample specimens (using the Ames Vestibular Research Facility or equivalent).
 - In-flight: Sacrifice, dissection, and fixation of 10 experimental and 10 control specimens at 90-day intervals.
 - Postflight: Sacrifice, dissection, and fixation of tissues; light and electron microscopy of labyrinths and neural tissues.
 - C. Sample Analysis:
 - In-flight: None.
 - Postflight: Analysis of labyrinths and neural tissues.
 - D. Experiment Controls:
 - In-flight: Half the sample held at 1 g.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board centrifuge capable of maintaining 50 experimental subjects at 1 g.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/90 day} \times 20 = 10 \text{ hr.}$
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-U.
 - B. Science Objectives: NS-2, NS-5.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of 1-g Centrifugation on Susceptibility to Space Motion Sickness in Squirrel Monkeys.
2. **PURPOSE/HYPOTHESIS:** To determine whether the onset of space motion sickness can be delayed by keeping animals on a centrifuge simulating Earth gravity after arrival in microgravity. To determine whether an animal which is readapted to 1 g on an on-board centrifuge after adapting to microgravity is any more or less susceptible to space motion sickness after being placed back into microgravity. To determine whether centrifuged animals readapt with a different rate than controls on return to Earth's gravity field.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The underlying mechanisms of space motion sickness are not well understood. These studies would determine whether it is a labile phenomenon; whether its probability of occurrence is influenced by reexposure to fractional gravity fields during spaceflight. These studies will also assess the efficacy of fractional gravity as a means of preventing space motion sickness in astronauts.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 motion-sickness-susceptible squirrel monkeys.
 - B. Measurements/Samples:
Preflight: Characterization of subject motion-sickness susceptibility in Ames Research Center Motion Sickness Laboratory.
In-flight: After 10, 20, 40, and 80 days of exposure to microgravity, centrifugation at 1 g for 24, 48, and 72 hr and subsequent testing for motion-sickness susceptibility.
Postflight: TBD.
 - C. Sample Analysis:
In-flight: Analysis and tabulation of motion-sickness susceptibility.
Postflight: None.
 - D. Experiment Controls:
In-flight: TBD depending on exact experiment conditions.
Ground-based: Same as in-flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board centrifuge which can apply a 1-g field to a freely moving squirrel monkey in a research animal holding facility cage; vestibular testing device capable of delivering provocative vestibular stimulation; and a motion-sickness sensor system.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/monkey} \times 4/90 \text{ day} = 2 \text{ hr} \times 4 = 8 \text{ hr}.$
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-V.
 - B. Science Objectives: NS-1, NS-6, NS-7, NS-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Production of Space Motion Sickness by Provocative Vestibular Stimuli During Adaptation to Microgravity and Fractional Gravity.
2. **PURPOSE/HYPOTHESIS:** To determine the effect of provocative vestibular stimuli on motion sickness susceptibility during adaptation to microgravity and to fractional gravity loads delivered by an on-board centrifuge.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Same as experiment NS-U.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 motion-sickness-susceptible squirrel monkeys (2 in ambient microgravity and 2 at a TBD fraction of Earth gravity provided by a centrifuge).
 - B. Measurements/Samples:
Preflight: Characterization of subject motion-sickness susceptibility in Ames Research Center Motion Sickness Laboratory.
In-flight: Application of provocative vestibular stimuli to animals at 10-day intervals to determine onset probability and severity of induced motion sickness.
Postflight: TBD.
 - C. Sample Analysis:
In-flight: Analysis and tabulation of motion-sickness susceptibility.
Postflight: None.
 - D. Experiment Controls:
In-flight: TBD depending on exact experiment conditions.
Ground-based: Same as in-flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board centrifuge which can apply a 1-gravity field to a freely moving squirrel monkey in a research animal holding facility cage and a vestibular testing device capable of delivering provocative vestibular stimulation.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/monkey} \times 8/90 \text{ day} = 4 \text{ hr} \times 4 = 16 \text{ hr}.$
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-W.
 - B. Science Objectives: NS-1, NS-2, NS-6, NS-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Provocative (Motion Sickness-Inducing) Stimuli on Vestibular Neurons and Reflexes During Adaptation to Microgravity.
2. **PURPOSE/HYPOTHESIS:** What are the effects of provocative vestibular stimuli on elements of central neural pathways and on vestibular reflexes during adaptation to microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Changes in vestibular reflexes (and their neural substrate) underlying adaptation to microgravity should be understood to formulate experiments examining the interactions among vestibular, visual, proprioceptive, and somatosensory inputs resulting from motions inducing space motion sickness.
4. **APPROACH:**
 - A. Number/Type Specimens: 4 motion-sickness-susceptible squirrel monkeys (2 experimental animals at ambient level of microgravity).
 - B. Measurements/Samples:
Preflight: Characterization of subject motion-sickness susceptibility in Ames Research Center Motion Sickness Laboratory.
In-flight: Application of provocative vestibular stimuli to animals on days 1, 3, 5, 10, 20, 40, and 80 while measuring vestibular reflexes and recording the activity of single vestibular system neurons.
Postflight: TBD.
 - C. Sample Analysis:
In-flight: Computer analysis of vestibular reflex and neural activity.
Postflight: TBD.
 - D. Experiment Controls:
In-flight: None.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vestibular testing device capable of delivering provocative vestibular stimulation.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-X.
 - B. Science Objectives: NS-1, NS-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Microgravity Exposure on the Labyrinth's Anatomic Development and Neural Connections.
2. **PURPOSE/HYPOTHESIS:** To determine the structural (anatomic) consequences of deprivation of vestibular inputs on the development of the labyrinth and its connections to other nervous system structures.
3. **PROGRAM RATIONALE/JUSTIFICATION:** In nervous system development and structural plasticity, one basic problem is the effect of sensory deprivation on developing or regenerating sensory pathways. Relatively brief periods of deprivation during early development may result in permanent deficits in nervous system structure and function (Fabricant report, p. 83). There is no other way to study the effect of proprioceptive deprivation on nervous system development than in a microgravity environment.
4. **APPROACH:**
 - A. Number/Type Specimens: 16 pregnant rats (in-flight-impregnated or Earth-impregnated) (8 in developmental facility, 8 centrifuge controls).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Vital signs daily; sacrifice, and histologically fix 2 specimens from each experimental and each control litter at embryonic day 18, at birth, and at 28 days of age.
Postflight: Light and electron microscopy.
 - C. Sample Analysis:
In-flight: None.
Postflight: Light and electron microscopy.
 - D. Experiment Controls:
In-flight: 8 animals held in home cages on a centrifuge at 1 g.
Ground-based: TBD.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Developmental facility; on-board centrifuge capable of maintaining 8 rats at 1-g in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/rat} \times 3/90 \text{ day} = 1.5 \text{ hr} \times 96 = 144 \text{ hr}.$
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-Y.
 - B. Science Objectives: NS-7, NS-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Fractional Gravity Loads on the Labyrinth's Anatomic Development and Neural Connections.
2. **PURPOSE/HYPOTHESIS:** To determine the degree to which such structural changes can be mitigated by exposure to partial gravitational loading using an on-board centrifuge.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is important to understand the consequences of exposure to microgravity on the development of neural structures and connections. If those structures and connections are affected by development in microgravity, it will be important to determine whether exposure to fractional gravity loads ameliorates all or part of the effects.
4. **APPROACH:**
 - A. Number/Type Specimens: 8 pregnant rats (ground- or in-flight impregnated) (2 at 0.25, 2 at 0.5, 2 at 0.75, and 2 at 1 g).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Vital signs daily; sacrifice, and histologically fix 2 specimens from each experimental and each control litter at embryonic day 18, at birth, and at 28 days of age.
Postflight: Light and electron microscopy.
 - C. Sample Analysis:
In-flight: None.
Postflight: Light and electron microscopy.
 - D. Experiment Controls:
In-flight: 1-g controls are on centrifuge with experimental animals.
Ground-based: TBD.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Variable-g centrifuge containing a development facility.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/rat} \times 3/90 \text{ day} = 1.5 \text{ hr} \times 48 = 72 \text{ hr}.$
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-Z.
 - B. Science Objectives: NS-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of "Gravity-Deprivation" on Nervous System Structures and Functions that Depend on Earth's Gravity for Normal Development.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of deprivation of vestibular and other proprioceptor inputs on the nervous system's development using reflexive neurophysiological techniques.
3. **PROGRAM RATIONALE/JUSTIFICATION:** On Earth, deprivation studies in neonatal animals, particularly those concerned with the visual system, have revealed how sensory experiences help to determine neuronal systems development. The extension of such studies to proprioceptive sensory systems opens up exciting new possibilities. The only way to deprive a developing animal of vestibular/proprioceptive information is to use the microgravity of space (Fabricant report, p. 76). See also rationale/justification for experiment NS-Y.
4. **APPROACH:**
 - A. Number/Type Specimens: 16 pregnant rats (in-flight-impregnated or Earth-impregnated) (8 in developmental facility, 8 centrifuge controls).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Vital signs daily and vestibular reflex testing of two specimens from each experimental and each control litter at birth, and at 7, 14, and 28 days of age.
Postflight: Analysis of in-flight data.
 - C. Sample Analysis:
In-flight: Analyze in-flight reflex data as collected.
Postflight: Detailed analysis of in-flight data.
 - D. Experiment Controls:
In-flight: 8 animals held in home cages on a centrifuge at 1 g.
Ground-based: TBD.
5. **SPACE STATION REQUIREMENTS:**
 - A. Special Equipment (other than common items): Centrifuge capable of maintaining 8 rats at 1-g in home cages and a developmental facility.
 - B. Estimated Total In-flight Crew Time (hrs/90 days, based on 1 g environment):
 $0.1 \text{ hr/rat/90 day} = 0.1 \text{ hr} \times 128 = 12.8 \text{ hr}.$
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-AA.
 - B. Science Objectives: NS-1, NS-6, NS-7, NS-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Does Fractional Gravitational Loading Reduce Microgravity-Related Developmental Anomalies of Nervous System Structures and Functions?
2. **PURPOSE/HYPOTHESIS:** To determine whether developmental anomalies in the functions of the vestibular reflex system can be offset or cancelled by fractional gravitational loads.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is important to understand basic mechanisms underlying nervous system development and whether exposure to microgravity interferes with those mechanisms. The ability of fractional gravitational loads to ameliorate such changes will provide important information about preventing developmental anomalies.
4. **APPROACH:**
 - A. Number/Type Specimens: 16 pregnant rats (in-flight-impregnated or Earth-impregnated) total (8 in developmental facility, 8 centrifuge controls).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Vital signs daily, and vestibular reflex testing of two specimens from each experimental and each control litter at birth, and at 7, 14, and 28 days of age.
Postflight: Analysis of data collected in-flight.
 - C. Sample Analysis:
In-flight: Analyze reflex data as collected.
Post-flight: Detailed analysis of in-flight data.
 - D. Experiment Controls:
In-flight: 8 animals held in home cages on a centrifuge at 1 g.
Ground-based: TBD.
5. **SPACE STATION REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board centrifuge with a developmental facility.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 12.8 hr.
 - C. Experiment Site: LSRF: Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-BB.
 - B. Science Objectives: MS/F-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Long-Duration Exposure to Microgravity and Fractional Gravity on Spinal Cord Motorneurons, Peripheral Nerve, and Motor Endplates of Anti-Gravity Muscles.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of microgravity on the structure, metabolic activity, and electrophysiology of neuromuscular units; to determine the time course and extent of recovery of these neuromuscular units upon return to Earth's gravity; and to evaluate fractional gravity's influence on preventing the effects of microgravity and on the extent and time course of recovery.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Little is known about changes in peripheral nerves and corresponding central motorneurons in the muscle atrophy which occurs during spaceflight. It is known, however, that there are changes in muscle fiber types, which suggests a modification in the innervation of the muscle fibers. Plasticity of central and peripheral neuromuscular systems must be understood for the development of countermeasures for muscle atrophy induced by microgravity exposure.
4. **APPROACH:**
 - A. Number/Type Specimens: 240 adult rats (60 animals held at ambient microgravity, 60 held at 1 g, and 60 each at 0.33 g and 0.67 g).
 - B. Measurements/Samples:
 - Preflight: TBD assessment of integrity of experimental animals' neuromuscular control systems.
 - In-flight: Vital signs daily; sacrifice, and fixation of tissues of 20 rats (5 microgravity, 5 1-g controls, and 5 from each fractional gravity group) on days 3, 5, 10, 20, 40 and 90; recording of motorneuron activity in 2 animals from each fractional gravity group on days 5 and 20, prior to sacrifice.
 - Postflight: Vital signs daily; sacrifice, and fixation of 5 animals from each group on postflight days 1, 3, 5, 10, 20 and 90; recording of motorneuron activity from two animals of each group prior to sacrifice.
 - C. Sample Analysis:
 - In-flight: TBD analysis of neurophysiological data as collected.
 - Postflight: TBD histological and histochemical processing, light and electron microscopy; and detailed analysis of motorneuron activity.
 - D. Experiment Controls:
 - In-flight: Controls held in home cages at either 1-g, 0.33 g or 0.66 g.
 - Ground-based: TBD.
5. **SPACE STATION REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board specimen centrifuge capable of providing 0.33 g, 0.66 g, and 1 g to rat specimens in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-CC.
 - B. Science Objectives: NS-1, NS-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Microgravity on Gravity Receptor Development Across Generations: Effects of Fractional Gravity Loads on Development Across Generations.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of microgravity on the structure and innervation patterns of gravity receptors and to assess long-term effects by growing multiple generations in microgravity and at various levels of fractional gravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This study will help to elucidate the role of gravity in molding the structure and function of gravity receptors. Specifically, it will contribute to an understanding of the extent to which gravity receptor development is dependent on genetic and environmental factors. It will also contribute to an understanding of the role of different levels of gravity on the structure and function of gravity receptors (i.e., Is there a "critical level" of fractional gravity below which significant changes will occur?).
4. **APPROACH:**
 - A. Number/Type Specimens: 6 adult breeding rats to be impregnated during spaceflight. (This experiment should be done with a number of species, but there is a large amount of data available on the rodent.)
 - B. Measurements/Samples:

Preflight: TBD baseline testing to ensure normality of animals.

In-flight: Sacrifice and fixation of 2 specimens from each litter born in space on postnatal days 1, 5 and 9; 2 specimens from each litter are to be reared to adulthood and bred, and the sacrifice of pups to be repeated. Experiment is to be repeated across five generations.

Postflight: 2 specimens from each litter in each generation are to be returned to Earth for TBD studies on readaptation to Earth gravity.
 - C. Sample Analysis:

In-flight: None.

Postflight: TBD light and electron microscopy, histochemistry, etc.
 - D. Expt. Controls (In-flight , Ground-based):

In-flight: Animals held at 1 g and at fractional gravity (0.33 g and 0.66 g) in home cages.

Ground-based: TBD.
5. **SPACE STATION REQUIREMENTS:**
 - A. Special Equipment (other than common items): On-board centrifuge capable of delivering 1 g and fractional gravity to rats in home cages.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):

0.5 hr/rat/90 day x 30 rats = 15 hr (x 3 for each gravity level = 45 hr).
 - C. Experiment Site: LSRF: Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-DD.
 - B. Science Objectives: NS-9.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Central Nervous System Metabolism During Spaceflight.
2. **PURPOSE/HYPOTHESIS:** Modifications of physiological function in altered gravity are mediated by changes in central nervous system function.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Measurement of metabolic activity in the brain, by measuring cytochrome oxidase levels, will identify and quantify such changes.
4. **APPROACH:**
 - A. Number/Type Specimens: 60 rats.
 - B. Measurements/Samples:
Preflight: Baseline studies.
In-flight: Brain tissue collected at wk 1, 2, 4, 8, 12 (6 at each wk); animals studied in microgravity and at fractional g; fixation of brains in vitro after saline flush in vivo.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of tissue collected in-flight.
 - D. Experiment Controls:
In-flight: TBD.
Ground-based: Preflight simulations, hypergravity studies, and postflight readaptation.
5. **SPACE STATION REQUIREMENTS:**
 - A. Special Equipment (other than common items): Perfusion capabilities in work station; variable-g centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 15 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Neurosciences NS-EE.
 - B. Science Objectives: NS-10.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Neurotransmitter Receptor Changes in Altered Gravity.
2. **PURPOSE/HYPOTHESIS:** Central nervous system functions and physiological regulation are modified by altered gravity. Changes in receptor number, function, and sensitivity will occur.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Neurotransmitter systems are known to be modified during spaceflight. Kinetics and transmitter system specificity, however, are not known.
4. **APPROACH:**
 - A. Number/Type Specimens: 30 rats.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Remove brain, freeze at wk 1, 2, 4, 8, 12 (6 animals per sample period).
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Histologic analysis of tissue collected in-flight.
 - D. Experiment Controls:
In-flight: TBD.
Ground-based: Preflight, postflight at 1 g and >1 g.
5. **SPACE STATION REQUIREMENTS:**
 - A. Special Equipment (other than common items): -70° freezer, snap freezer, and variable-g centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment):
 $0.5 \text{ hr/rat/90 day} \times 30 = 15 \text{ hr}.$
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

NEUROSCIENCES HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE									
		NS A	NS B	NS C	NS D	NS E	NS F	NS G	NS H	NS I	NS J
Crew time (hr/90 day)		10	15	TBD	30	45	TBD	TBD	TBD	TBD	TBD
Item											
Animal perfusion kit	1										
Cage cleaner	31	1	1	1	1	1	1	1	1	1	1
Development module	4										
Fixation kit	12	1	1	1	1	1					
Freezer (-20° C)	11	1	1	1	1	1					
Freezer (-70° C)	1										
G control centrifuge (10')	5										
G control centrifuge (5')	7	1			1						
Guillotine	12	1	1	1	1	1					
Hand wash facility	31	1	1	1	1	1	1	1	1	1	1
Motion sickness indicator system	3										
Multi-purpose work bench	31	1	1	1	1	1	1	1	1	1	1
Primate optokinetic test device	2										
Rodent food	16	1	1	1	1	1	1	TBD	TBD		
Rodent module	16	1	1	1	1	1	1	TBD	TBD		
Rodent water	16	1	1	1	1	1	1	TBD	TBD		
Squirrel monkey food	13							TBD	TBD	1	1
Squirrel monkey module	13							TBD	TBD	1	1
Squirrel monkey water	13							TBD	TBD	1	1
Surgery/dissection kit	12	1	1	1	1	1					
Trash compactor	31	1	1	1	1	1	1	1	1	1	1
Variable-G centrifuge (13')	13		1			1		1	1		
Vestibular Research Facility	14							1	1		1

NEUROSCIENCES HARDWARE USE AND CREW TIME (BY EXPERIMENT) (CONTINUED)

	EXPERIMENT CODE										
	NS K	NS L	NS M	NS N	NS O	NS P	NS Q	NS R	NS S	NS T	NS U
Crew time (hr/90 day)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	10	8
Item											
Animal perfusion kit											
Cage cleaner	1	1	1	1	1	1	1	1	1	1	1
Development module											
Fixation kit										1	
Freezer (-20° C)										1	
Freezer (-70° C)											
G control centrifuge (10')				1	1	1		1			1
G control centrifuge (5')									1	1	
Guillotine										1	
Hand wash facility	1	1	1	1	1	1	1	1	1	1	1
Motion sickness indicator system											1
Multi-purpose work bench	1	1	1	1	1	1	1	1	1	1	1
Primate optokinetic test device						1	1				
Rodent food									1	1	
Rodent module									1	1	
Rodent water									1	1	
Squirrel monkey food	1	1	1	1	1	1	1	1			1
Squirrel monkey module	1	1	1	1	1	1	1	1			1
Squirrel monkey water	1	1	1	1	1	1	1	1			1
Surgery/dissection kit										1	
Trash compactor	1	1	1	1	1	1	1	1	1	1	1
Variable-G centrifuge (13')	1		1				1				
Vestibular Research Facility	1	1	1	1	1		1	1	1		1

NEUROSCIENCES HARDWARE USE AND CREW TIME (BY EXPERIMENT) (CONCLUDED)

	EXPERIMENT CODE									
	NS V	NS W	NS X	NS Y	NS Z	NS AA	NS BB	NS CC	NS DD	NS EE
Crew time (hr/90 day)	16	TBD	144	72	12.8	12.8	TBD	45	15	15
Item										
Animal perfusion kit									1	
Cage cleaner	1	1	1	1	1	1	1	1	1	1
Development module			1	1	1	1				
Fixation kit			1	1			1	1	1	1
Freezer (-20° C)			1	1			1	1	1	
Freezer (-70° C)										1
G control centrifuge (10')										
G control centrifuge (5')			1		1	1				
Guillotine			1	1			1	1	1	1
Hand wash facility	1	1	1	1	1	1	1	1	1	1
Motion sickness indicator system	1	1								
Multi-purpose work bench	1	1	1	1	1	1	1	1	1	1
Primate optokinetic test device										
Rodent food			1	1	1	1	1	1	1	1
Rodent module			1	1	1	1	1	1	1	1
Rodent water			1	1	1	1	1	1	1	1
Squirrel monkey food	1	1								
Squirrel monkey module	1	1								
Squirrel monkey water	1	1								
Surgery/dissection kit			1	1			1	1	1	1
Trash compactor	1	1	1	1	1	1	1	1	1	1
Variable-G centrifuge (13')	1			1			1	1	1	1
Vestibular Research Facility	1	1								

L. PLANT PHYSIOLOGY

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RATIONALE FOR PLANT PHYSIOLOGY EXPERIMENTS ON SPACE STATION

The space station will provide a first opportunity for the United States to study plant growth, development, and metabolism in the microgravity and radiation environment of space for a duration at least equal to a complete seed-to-seed life cycle. Answers to the four basic questions below are fundamental to understanding plant growth both on Earth and in space. These answers will apply directly to the future development of Controlled Ecological Life Support Systems for long-duration manned spaceflight and planetary habitation.

1. How does a plant sense gravity, and how does it transmit this information to other parts of the plant which respond to gravity?
2. How does gravity affect the development of a plant?
3. What role does gravity play in regulating metabolic processes in plants?
4. How do plants respond to other environmental influences such as light, mechanical stimulation, and magnetic fields in the absence of gravity?

PRIORITIZED SCIENCE OBJECTIVES FOR PLANT PHYSIOLOGY

- PL-1** Determine the role of gravity in control of development at the whole plant, organ, and cellular levels, including the use of variable gravity to manipulate and understand the thresholds. (Red Book-1)
Experiments: PL-A, B, C, E, H, K, L, O
- PL-2** Determine the role of gravity in regulating metabolic and cellular processes in plants. (Red Book-2)
Experiments: PL-A, B, C, D, E, G, H, I, J, K, L, O, Q,
- PL-3** Determine mechanism(s) of gravity sensing and transduction of this information into tropic and nastic responses, including the use of variable gravity to manipulate and understand the thresholds. (Red Book-4)
Experiments: PL-A, B, F, H, I, L, M, N, P

PLANT PHYSIOLOGY EXPERIMENT TITLES

Code	Title	Objective
PL-A	Optimization of Plant Nutrient and Water Supply Systems THIS EXPT ALSO LISTED AS CL-A	PL-1, PL-2, PL-3 (CL-1, CL-2, CL-3)
PL-B	Optimization of Plant Support and Orientation Mechanisms for Use in Microgravity THIS EXPT ALSO LISTED AS CL-B	PL-1, PL-2, PL-3 (CL-1, CL-2, CL-3)
PL-C	Multiple Generation Plant Growth THIS EXPT ALSO LISTED AS CL-C	PL-1, PL-2
PL-D	Effect of Microgravity on Gas Exchange from a Higher Plant	PL-2
PL-E	Role of Microgravity in Control of Development at the Organ and Cellular Level	PL-1, PL-2
PL-F	Threshold of Gravity for Gravitropism	PL-3
PL-G	Ethylene Production under Microgravity and in Response to Clinostating	PL-2
PL-H	Mechanisms for Control of Atmospheric Gas Concentrations and Temperature in Microgravity THIS EXPT ALSO LISTED AS CL-D	PL-1, PL-2, PL-3 (CL-1, CL-2, CL-3)
PL-I	Effect of Microgravity on Amyloplast Development	PL-2, PL-3
PL-J	Effects of Microgravity on Various Metabolic and Cellular Processes in Plants	PL-2
PL-K	Role of Microgravity in Lignification and Silicification	PL-1, PL-2
PL-L	Role of Gravity in the Control of Development at the Whole Plant, Organ, and Cell Levels	PL-1, PL-2, PL-3
PL-M	Determination of Gravity Threshold for Plant Circumnutation	PL-3
PL-N	Reciprocity of Gravitational Effects on Plant Gravitropism; Effect of Gravity on Hormone Distribution	PL-3
PL-O	Interactions of Gravity and Radiation on Mutation Rate and Radiation Damage	PL-1, PL-2
PL-P	Determination of Relative Influences of Amyloplast Location and of Amyloplast Pressure on Gravitropism Response	PL-3
PL-Q	Role of Gravity in Secondary Metabolite Production	PL-2

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-A. (NOTE: This experiment duplicates CELSS experiment CL-A.)
 - B. Science Objectives: PL-1, PL-2, PL-3 (CL-1, CL-2, CL-3).
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Optimization of Plant Nutrient and Water Supply Systems.
2. **PURPOSE/HYPOTHESIS:** To determine the optimal method for supplying nutrients and water to plants in microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This information is required to grow plants for conducting experiments in microgravity.
4. **APPROACH:**
 - A. Number/Type Specimens: Ten groups of 10-15 plants per group of various plants (e.g., *Arabidopsis*, lettuce, wheat).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Environmental control for plant habitat, whole plants harvested at weekly intervals.
Postflight: Dry weights of plant tissue.
 - C. Sample Analysis:
In-flight: Environmental control for plant habitat.
Postflight: Chemical composition of plant tissue.
 - D. Experiment Controls:
In-flight: Although flight controls would not be required for all experiments, the best microgravity methods would ultimately have to be compared with a 1-g centrifuge control.
Ground-based: Controls for all methods tested.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, freezer, and 1-g centrifuge (at some point).
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 25 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-B. (NOTE: This experiment duplicates CELSS experiment CL-B.)
 - B. Science Objectives: PL-1, PL-2, PL-3 (CL-1, CL-2, CL-3).
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Optimization of Plant Support and Orientation Mechanisms for Use in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To identify the optimal methods for holding and orienting plants in microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This information is required to grow plants for conducting experiments in microgravity.
4. **APPROACH:**
 - A. Number/Type Specimens: Ten groups of 10-15 plants per group of various plants (e.g., *Arabidopsis*, lettuce, wheat).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Environmental control for plant habitat, whole plants harvested at weekly intervals, and video monitoring of plant growth.
Postflight: Dry weights of plant tissue.
 - C. Sample Analysis:
In-flight: Environmental control for plant habitat.
Postflight: Chemical analysis of plant tissue.
 - D. Experiment Controls:
In-flight: 1-g centrifuge control.
Ground-based: Controls for all methods.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, freezer, 1-g centrifuge, and plant habitat video monitor.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 35 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: ☐ Platform: ☐

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-C. (NOTE: This experiment duplicates CELSS experiment CL-C.)
 - B. Science Objectives: PL-1, PL-2 (CL-1).
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Multiple Generation Plant Growth.
2. **PURPOSE/HYPOTHESIS:** To evaluate the growth of plants over two generations under spaceflight conditions.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Multiple generation capabilities are required for plant use in CELSS, and are desirable for plant experiments.
4. **APPROACH:**
 - A. Number/Type Specimens: Two groups of 50 plants per group of a fast cycle plant such as *Arabidopsis*.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Telemonitoring, environmental control for plant habitat.
Postflight: Analysis of a portion of space-grown seeds by growing them on Earth.
 - C. Sample Analysis:
In-flight: Environmental control for plant habitat; biomass determination.
Postflight: Biomass determination.
 - D. Experiment Controls:
In-flight: 1-g centrifuge control.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, plant habitat telemonitor, and 1-g centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 10 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-D.
 - B. Science Objectives: PL-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Microgravity on Gas Exchange from a Higher Plant.
2. **PURPOSE/HYPOTHESIS:** There have been indications that microgravity may influence stomatal control so as to influence CO₂/H₂O exchange. The purpose of this experiment is to compare CO₂ and H₂O exchange under light and dark, and in microgravity versus 1 g.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This information is essential to determine water-use efficiency of plants in space. This is needed in order to assess the amounts of CO₂ and H₂O that need to be supplied to plants growing in space. In addition, it should provide information about microgravity's influence on H₂O transport, respiration, and stomatal control.
4. **APPROACH:**
 - A. Number/Type Specimens: Four groups of 4-6 plants/species such as *Helianthus*, tomato or pea. Plants germinated and grown in plant habitat.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Continuously monitor CO₂ and H₂O under light and dark, at microgravity (no centrifuge) versus continuous 1-g centrifuge. Need to be monitored and recorded automatically for at least 2 days. Four sets of 4-6 plants: 1) light, 0 g; 2) light, 1 g; 3) dark, 0 g; and 4) dark, 1 g.
Postflight: None.
 - C. Sample Analysis:
In-flight: As above.
Postflight: None.
 - D. Experiment Controls:
In-flight: As above, 1-g centrifuge is needed in control.
Ground-based: Same.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, 1-g centrifuge equipped with infrared gas analyzer for CO₂, humidity sensor for H₂O.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-E.
 - B. Science Objectives: PL-1, PL-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): (A)PC1/Role of Microgravity in Control of Development at the Organ and Cellular Level.
2. **PURPOSE/HYPOTHESIS:** Higher plant development is characterized by orderly patterned and directed cell division in growing regions and meristems. To what extent will orientation of planes of division and organ formation be affected in the absence of (or perturbation of) directional influences such as hormones and physiological gradients?
3. **PROGRAM RATIONALE/JUSTIFICATION:** To understand the role of gravity in the control of development at the organ and cellular level. To understand the role of gravity in regulating metabolic and cellular processes in plants. To establish the effects of microgravity on developmental patterns.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 specimens each of a dicotyledonous species such as *Arabidopsis* or equivalent plant with fast life cycle; a monocotyledonous species such as oat or corn; and appropriate plant cell and tissue cultures which can organize.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Activation or initiation of development; fixation for cytological, histological and biochemical sampling and cryogenic storage for postflight analysis, video monitor.
Postflight: Analysis of samples.
 - C. Sample Analysis:
In-flight: Gas analysis for analysis on Earth. Temporal fixation and cryogenic and cryogenic processing and storage at specified intervals.
Postflight: Analysis of gas samples.
 - D. Experiment Controls:
In-flight: A 1-g centrifuge control population will be maintained as well as a 0-g control group, a 0.16-g (Lunar) control group, and a 0.38-g (Martian) control group.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, variable-gravity centrifuge, video monitor, in-flight fixation; and cryogenic processing and storage.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-F.
 - B. Science Objectives: PL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): (A)PC2 Threshold of Gravity for Gravitropism.
2. **PURPOSE/HYPOTHESIS:** Plants undergo gravitropic curvature in response to 1 g, but not to less than 10^{-4} g (microgravity). The question is, what would the response be to gravity values between 10^{-4} and 1 g, and is there a gravity threshold? Clinostat experiments have suggested that a threshold of about 10^{-2} g exists, but it is very uncertain that these measurements are valid. The gravity threshold is needed to help determine whether it is the pressure of amyloplasts or their position that is sensed.
3. **PROGRAM RATIONALE/JUSTIFICATION:** We need to understand the mechanism by which plants perceive gravity. To do this, we must understand the dosage-response curve for the process.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 seedlings /gravity treatment = 84 seedlings, maize coleoptiles (4 days), maize roots (3 days old), or *Helianthus* hypocotyls (6 days).
 - B. Measurements/Samples:

Preflight: None.

In-flight: Plants are placed on the centrifuge and centrifuged for 30 min at speeds sufficient to produce 1, 0.3, 0.1, 3×10^{-2} , 3×10^{-3} , and 10^{-3} g, then returned to control conditions. One group of plants is not centrifuged. Coleoptile and root orientation determined by video monitoring at 30, 60, 90, and 120 min. Curvature determined and plotted versus gravity.

Postflight: None.
 - C. Sample Analysis:

In-flight: As above.

Postflight: None.
 - D. Experiment Controls:

In-flight: The noncentrifuged plants are the control.

Ground-based: Controls are also desired, to see if 1-g curvature on centrifuge = 1-g curvature on Earth.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, variable-gravity centrifuge, and video monitor.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-G.
 - B. Science Objectives: PL-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Ethylene Production Under Microgravity and in Response to Clinostating.
2. **PURPOSE/HYPOTHESIS:** Existing plant space experiments have indicated that plants in microgravity can produce large amounts of ethylene, but we do not know whether this is a response to microgravity or to other factors. Likewise, plants on a clinostat produce ethylene, but we do not know whether this is in response to uncompensated gravity or to centrifugal force.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Plants cannot be grown successfully in space unless they can be grown in the absence of any appreciable concentrations of ethylene, because ethylene causes abnormal plant growth. Therefore we must know when and why plants in microgravity produce ethylene.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 tomato seedlings (at least 6/treatment) (2 wk old).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Plants are run for 24 hr on: 1) no centrifuge, no clinostat (control), 2) no centrifuge but 1-rpm clinostat (clinostat control), 3) 1-g centrifuge, and 4) 1-g centrifuge and 1-rpm clinostat. Ethylene production is monitored by gas chromatograph at 6-hr intervals.
Postflight: None.
 - C. Sample Analysis:
In-flight: As above.
Postflight: None.
 - D. Experiment Controls:
In-flight: 1-g centrifuge and clinostat as described above.
Ground-based: Same as in-flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, with gas chromatograph monitor and 1-rpm clinostat to handle single plants.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 3 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-H. (NOTE: This experiment duplicates CELSS experiment CL-D.)
 - B. Science Objectives: PL-1, PL-2, PL-3 (CL-1, CL-2, CL-3).
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Mechanisms for Control of Atmospheric Gas Concentrations and Temperature in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To identify methods for control of atmospheric temperature and gas concentrations for plant growth and development experiments.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Control of atmospheric temperature and gas concentrations requires circulation of the atmosphere. Atmosphere movement induces gravitational forces on plants. Thus, control must be achieved with minimum atmospheric movement.
4. **APPROACH:**
 - A. Number/Type Specimens: Five groups of 10-15 various plants per group, lettuce, wheat, and soybean.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Each group will be subjected to different patterns and velocities of atmospheric circulation (temperature and gas concentrations); environmental control for plant habitat.
Postflight: Harvest plants at end of experiment.
 - C. Sample Analysis:
In-flight: Environmental control for plant habitat.
Postflight: Dry weight.
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat and centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-I.
 - B. Science Objectives: PL-2, PL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Microgravity on Amyloplast Development.
2. **PURPOSE/HYPOTHESIS:** Gravity perception in higher plants is achieved primarily by means of statoliths or amyloplasts in specialized cells (statocytes). We need to ascertain whether microgravity has any effect on the development and formation of amyloplasts.
3. **PROGRAM RATIONALE/JUSTIFICATION:** To understand the nature and role of gravity-sensing elements in microgravity and to discover whether sensing and transduction can be uncoupled or affected at the level of the amyloplast.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 each monocots such as oats or maize, and a dicot such as pea, or *Arabidopsis*.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Initiate growth from seeds and prepare samples by fixation at 2-5 days. Video monitor 2-3 times each day.
Postflight: Analysis of samples.
 - C. Sample Analysis:
In-flight: Fixation for subsequent analysis.
Postflight: Analysis of samples.
 - D. Experiment Controls:
In-flight: 1-g centrifuge, 0 g.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, 1-g centrifuge, video monitor, and in-flight fixation apparatus.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-J.
 - B. Science Objectives: PL-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Microgravity on Various Metabolic and Cellular Processes in Plants.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of microgravity on various metabolic and cellular processes such as cell division, nutrient uptake and kinetics, and ion distribution.
3. **PROGRAM RATIONALE/JUSTIFICATION:** To understand the role of gravity in regulating metabolic and cellular processes in plants such as cell division, nutrient uptake, and ion distribution.
4. **APPROACH:**
 - A. Number/Type Specimens: Aseptically cultured cells, tissues, organs, and plantlets.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Activate quiescent cells into division and expose to fixation at 2- to 24-hr intervals.
Postflight: Analysis of samples.
 - C. Sample Analysis:
In-flight: None.
Postflight: Microscopy, radioactive counting, and biochemical analysis of cryogenically processed materials.
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): 1-g centrifuge, cell culture apparatus, in-flight fixation apparatus, and cryogenic processing and storage.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-K.
 - B. Science Objectives: PL-1, PL-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): (W)PC10/Role of Gravity in Lignification and Silicification (ARC book expt. # 10).
2. **PURPOSE/HYPOTHESIS:** One structural response to gravitational stress or gravity load in woody plants on Earth is lignification. Certain grasses respond to this stress by showing silicification. We do not know the extent to which these responses are due to weight of plant organs, to a graviperception mechanism, or to other factors. We need to understand the role of gravity in these responses.
3. **PROGRAM RATIONALE/JUSTIFICATION:** To understand the role of gravity in control of development at the organ and whole plant level. To understand the role of gravity in regulating metabolic and cellular processes in plants.
4. **APPROACH:**
 - A. Number/Type Specimens: 12 to 24 specimens each, pine, rice, or other species known to be good lignin formers or to undergo silicification.
 - B. Measurements/Samples:

Preflight: Chemically determine the amount of lignification in pine to determine morphological and anatomical distribution of lignin.

In-flight: Fix at various times.

Postflight: None.
 - C. Sample Analysis:

In-flight: None.

Postflight: Conduct microscopic, enzymatic, and chemical analyses.
 - D. Experiment Controls:

In-flight: Variable-gravity centrifuge controls, including 0 g.

Ground-based: Same.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-L.
 - B. Science Objectives: PL-1, PL-2, PL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): (W)PC6/Role of Gravity in the Control of Development at the Whole Plant, Organ, and Cell Levels.
2. **PURPOSE/HYPOTHESIS:** Morphogenesis and development of plants are influenced by gravity. By varying the gravity levels at various critical phases of development, one can discover the thresholds. (This experiment is an important follow-up to science objective 1, experiment C.)
3. **PROGRAM RATIONALE/JUSTIFICATION:** To understand the role of gravity in control of development at the whole plant, organ, and cell levels. To understand the role of gravity in regulating metabolic and cellular processes in plants. To understand the mechanisms of gravity sensing and transduction.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 to 48 plants per group, seed plants with a short life cycle like *Arabidopsis*, or various aseptic cell and/or tissue cultures.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Video monitoring; fixation at 12- to 48-hr intervals; tissue samples for cryogenic storage.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Microscopic and biochemical analyses.
 - D. Experiment Controls:
In-flight: Variable-gravity centrifuge.
Ground-based: Same.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, variable-gravity centrifuge, video monitor, and in-flight fixation apparatus.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-M.
 - B. Science Objectives: PL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Determination of Gravity Threshold for Plant Circumnutation.
2. **PURPOSE/HYPOTHESIS:** There have been two major theories to explain the control of plant circumnutation: a theory postulating endogenous rhythm control, and a theory postulating a gravity-controlled compensation mechanism. The Brown HEFLEX experiment indicated that in microgravity some of the circumnutation disappeared, but some persisted. This could indicate that the gravity threshold for circumnutation is less than 10^{-4} g (microgravity), or it could mean that part of the circumnutation is gravity-insensitive, while the rest has a threshold greater than 10^{-4} g. This experiment should distinguish between these two alternatives.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This will provide basic information about the role of gravity in nastic responses in plants. It should provide significant insight into the question of whether there is any gravity-independent, endogenous circumnutation process.
4. **APPROACH:**
 - A. Number/Type Specimens: 10 plants per gravity level (probably as series of replicants), *Helianthus* seedlings, 4-6 days old.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Germinate plants on 1-g centrifuge, then remove to variable-g centrifuge and run at 10^{-1} , 10^{-2} , and 10^{-3} g for 6 hr. Monitor stem position by video from above, and growth by horizontal video. Obtain data on each plant once every 10 min.
Postflight: None.
 - C. Sample Analysis:
In-flight or postflight: Analyze video pictures to give amplitude and period of circumnutation. Plot each versus log gravity.
 - D. Experiment Controls:
In-flight: 1-g (remains on centrifuge) and microgravity (no centrifuge).
Ground-based: Same.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, video monitor.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-N.
 - B. Science Objectives: PL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): (A)PC2/Reciprocity of Gravitational Effects on Plant Gravitropism; Effect of Gravity on Hormone Distribution.
2. **PURPOSE/HYPOTHESIS:** Some responses of plants to environmental cues are to the amount of stimulus, others to the delivery rate of stimuli. Plants respond to altered gravity vectors by showing growth curvature (gravitropism). The question is whether they respond only to length of time of altered gravity, or also to the product of time versus gravity. If the latter, the response is said to show reciprocity (as does phototropism). One major theory of plant gravitropism says that after the altered gravity is sensed, there is a redistribution of the hormone auxin from the upper to the lower side. Such a redistribution has been measured, but it is not clear if it occurs rapidly enough to explain gravitropic curvature. This will also be tested in this experiment.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This experiment would provide basic information about the way in which plants sense gravity and respond to it. Knowledge about the presence or absence of reciprocity is needed in order to test several theories about how plant cells perceive gravity.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 per experiment, 4-day maize roots, 5-day maize coleoptiles, 5-day *Helianthus* hypocotyls (seedlings).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Seeds are germinated without centrifugation. At start of experiment, seedlings are placed on the centrifuge so as to give a lateral gravity stimulation. Plants are given 2 min at 1 g, 4 min at 0.5 g, 10 min at 0.2 g, and 20 min at 0.1 g. Curvature over next 2 hr determined on half the samples. Rest are bisected at 0, 10, and 20 min after end of centrifugation, and frozen cryoscopically for later hormone assays.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Indole-3-acetic acid (IAA) levels measured by radioimmune assay (RIA) on two halves of each section. Curvature determined from video imaging of organs over 2 hr after centrifugation. Plot curve versus gravity x time.
 - D. Experiment Controls:
In-flight: Bisected, noncentrifuged organs for IAA analysis. Plants given vertical 2 min x 1-g centrifugation, to make certain centrifugation itself is not affecting hormone levels.
Ground-based: Same.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, variable-gravity centrifuge, apparatus for cryoscopic freezing and storage, and organ bisector.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-O.
 - B. Science Objectives: PL-1, PL-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Interactions of Gravity and Radiation on Mutation Rate and Radiation Damage.
2. **PURPOSE/HYPOTHESIS:** To ascertain any modifying effect of spaceflight or weightlessness on radiation damage and mutation rate. To discover antagonisms or synergisms of spaceflight conditions on damage.
3. **PROGRAM RATIONALE/JUSTIFICATION:** To understand the role of gravity in regulating metabolic and cellular processes in plants. To delineate the potential interactions of radiation and microgravity on plant development.
4. **APPROACH:**
 - A. Number/Type Specimens: Seeds of *Arabidopsis*, petunia, maize, or tomato at varying degrees of hydration.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Seeds exposed to radiation for various lengths of time at various gravity levels, then returned to Earth.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Mutation analysis.
 - D. Experiment Controls:
In-flight: Variable-gravity centrifuge.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat and variable-gravity centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-P.
 - B. Science Objectives: PL-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Determination of Relative Influences of Amyloplast Location and of Amyloplast Pressure on Gravitropism Response.
2. **PURPOSE/HYPOTHESIS:** Gravitropism occurs when the altered gravity vector is sensed by movement of amyloplasts to the lateral walls of cells. One theory says that gravisensing is due to the pressure of the amyloplasts on lateral wall endoplasm reticulum or such, while a second hypothesis is that it is only the location that affects gravitropism.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This will provide new and important information on the means by which gravity is sensed by plant cells.
4. **APPROACH:**
 - A. Number/Type Specimens: 10 each 4-day corn roots, 5-day corn coleoptiles.
 - B. Measurements/Samples:
Preflight: None.
In-flight: 10-min lateral centrifugation, or continuous centrifugation. Curvature video monitored over next 2 hr. Harvest organ at end of 2 hr and fix in situ.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Determine location of amyloplasts.
 - D. Experiment Controls:
In-flight: Curvature under continuous 1-g centrifugation and curvature under no centrifugation.
Ground-based: Same.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, 1-g centrifuge, and fixation apparatus for light microscopy.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Plant Physiology PL-Q.
 - B. Science Objectives: PL-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): The Role of Gravity in Secondary Metabolite Production.
2. **PURPOSE/HYPOTHESIS:** To test the effects of microgravity on secondary metabolite production. In microgravity there is no polarity, no buoyancy, no convective current, and no stratification of layers, and therefore surface tension dominates. These factors will have a major impact on cell metabolism that will be reflected in secondary metabolite production and accumulation.
3. **PROGRAM RATIONALE/JUSTIFICATION:** To understand the role of gravity in regulating and modulating metabolic and cellular processes in plants.
4. **APPROACH:**
 - A. Number/Type Specimens: Cell, tissue, organ, or plant cultures of various species known to produce substances such as cyanogenic glycosides or alkaloids.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Samples will be activated or initiated and periodically sampled (intervals from 2 to 48 hr).
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Microscopy and chemical analysis.
 - D. Experiment Controls:
In-flight: 1-g centrifuge
Ground-based: Same.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Plant habitat, in-flight fixation apparatus, and cryogenic processing other chemical fixation.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

PLANT PHYSIOLOGY HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE													
		PL D	PL E	PL F	PL G	PL I	PL J	PL K	PL L	PL M	PL N	PL O	PL P	PL Q	
Crew time (hr/90 day)		2	1	2	3	1	1	1	1	2	2	1	2	1	
Item															
Autoclave	2		1											1	
Cell culture apparatus	4		1			1	1							1	
Clinostat	2				1									1	
Experiment control computer	8	1	1		1	1		1		1	1			1	
Fixation kit	7		1			1	1	1	1				1	1	
Freezer, cryo (-196° C)	5		1				1		1		1			1	
G control centrifuge (small)	3		1				1							1	
Gas chromatograph	2				1									1	
Hand wash facility	13	1	1	1	1	1	1	1	1	1	1	1	1	1	
Humidity sensor for H2O	1	1													
Infrared gas analyzer for CO2	1	1													
Media	3		1	1			1								
Microscope,dissecting	5		1			1	1		1					1	
Multi-purpose work bench	13	1	1	1	1	1	1	1	1	1	1	1	1	1	
Organ bisector	1										1				
Plant gas supplies	13	1	1	1	1	1	1	1	1	1	1	1	1	1	
Plant habitat	13	1	1	1	1	1	1	1	1	1	1	1	1	1	
Plant harvesting kit	7	1	1						1		1	1	1	1	
Plant nutrient supply	13	1	1	1	1	1	1	1	1	1	1	1	1	1	
Radiation dosimeter (passive)	1											1			
Refrigerator (4°)	7		1			1	1	1	1				1	1	
Seed planting kit	7	1	1			1			1	1	1	1			
Surgery/dissection kit	4		1			1			1		1				
Trash compactor	13	1	1	1	1	1	1	1	1	1	1	1	1	1	
Variable-G centrifuge (13')	11	1	1	1	1	1		1	1	1	1	1	1		
Video camera, recorder, supplies	6		1	1		1		1	1	1					
Note: Equipment for PL-A, PL-B, PL-C and PL-H are not listed here because these experiments duplicate Cl-A, Cl-B, Cl-C and CL-D respectively and the equipment items are listed with those experiments.															

M. RADIOBIOLOGY

RATIONALE FOR RADIOBIOLOGY EXPERIMENTS ON SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR RADIOBIOLOGY

RADIOBIOLOGY EXPERIMENT TITLES

RADIOBIOLOGY EXPERIMENT DESCRIPTIONS

RADIOBIOLOGY EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

RATIONALE FOR RADIOBIOLOGY EXPERIMENTS ON SPACE STATION

The environment of space is not benign. The background radiation on the space station will be an important experimental variable to which all on-board living organisms will be exposed. It will probably set the limits on total mission time for human crew members and be an increasingly important variable for long-term developmental experiments with animals and plants. It will be critical to conduct accurate dosimetry on the space station to obtain the total dose and percent contribution from each kind of radiation (protons, neutrons, and heavy ions). These data will be used to determine the allowable exposure to radiation for the crew and determine limits for research specimens that may occupy the station longer than the proposed 90-day cycle for humans.

The baseline data gathered during early experiments on the space station will be used for determining shielding requirements and other countermeasures. Little is currently known regarding the biological effects of the anticipated exposures on space station to particulate radiations and especially high-energy particles. Experiments should also evaluate the radiation hazards from major solar flares and potential nuclear accidents (Earth-based or space station-based) while on orbit.

Whenever possible, the animal experiments should be designed to confirm and extend ground-based experiments conducted during the last two decades. An earlier USAF/NASA study which examined the effects of radiation on Rhesus monkey lifespan should be reviewed and similar studies which use human surrogates for subjects should be conducted. Based on previous studies, we believe that rodents are likely to give radiation responses that are spuriously high when compared to humans. If rodents are used, studies should be conducted toward developing a "transfer function" from rodents to primates.

PRIORITIZED SCIENCE OBJECTIVES FOR RADIOBIOLOGY

- RA-1** Evaluate the radiation environment within space vehicles as a function of long duration in space, vehicle construction materials, radiation type, to include not only total absorbed dose, but also information on the contribution of high-linear energy transfer (LET) particles and LET spectra, and orbital altitude to geosynchronous earth orbit (GEO). (Red Book-1)
Experiments: RA-A, B, C
- RA-2** Determine the risks of cancer, cataract formation, chromosomal aberrations, retinal damage, damage to hair follicles (estimate high-energy events), damage to stem cell populations (skin, testes, spermatogenesis), gut hematological effects, behavioral decrements, and opportunistic infections indicating deterioration of the immune system and wound healing. (Red Book-3)
Experiments: RA-D, E, F, G, H, I, L
- RA-3** Develop a measurement refinement of the current "passive" dosimeter and real-time active measurements for on-board readout which identify types of radiation and energy spectra. (Red Book-2)
Experiments: RA-J
- RA-4** Behavioral studies. (Red Book-None)
Experiments: RA-K

RADIOBIOLOGY EXPERIMENT TITLES

Code	Title	Objective
RA-A	Space Dosimetry	RA-1
RA-B	Radiation Measurements in "Biostack"-Type Experiments	RA-1
RA-C	Radiobiology of Very High Energy "Hadronic" Effects and Electromagnetic "Cascades"	RA-1
RA-D	Effects of Space Radiation on the Retina	RA-2
RA-E	Possible Cataract Formation/Hazard During Spaceflight	RA-2
RA-F	Effects of Space Radiation on Hair Follicles	RA-2
RA-G	Radiation Damage to Stem Cells of Skin	RA-2
RA-H	Effect of Space Radiation on Spermatogenesis and Intestinal Villi	RA-2
RA-I	Effect of Space Environment on Murine Hematopoietic Stem Cells	RA-2
RA-J	Refinement of Radiation Dosimetry	RA-3
RA-K	Alteration in the Length and Number of Synapses in the CA-1 Area of the Hippocampus	RA-4
RA-L	The Response of the Lungs to Cosmic Radiation	RA-2

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-A.
 - B. Science Objectives: RA-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Space Dosimetry.
2. **PURPOSE/HYPOTHESIS:** Measure radiation on board space station at all animal locations.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Certain experiments may be sensitive to radiation. We need accurate information about the effects of radiation exposure (linear energy transfer (LET) spectrum, high atomic number energy (HZE) particle, etc.) upon these experiments. In case of solar flares, all experiments will need radiation exposure information.
4. **APPROACH:**
 - A. Number/Type Specimens: Dosimeter to be used for primates/rats/plant seeds, etc.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Use passive and active dosimeters to measure radiation fields in the safe haven area of the spacecraft.
Postflight: None.
 - C. Sample Analysis:
In-flight: Read dosimeter.
Postflight: Develop passive dosimeters.
 - D. Experiment Controls: See C.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Passive dosimeter. Active dosimeter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 3 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-B.
 - B. Science Objectives: RA-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Radiation Measurements in "Biostack"-Type Experiments.
2. **PURPOSE/HYPOTHESIS:** Study effects of space radiation on small organisms.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Certain kinds of small organisms which are sensitive to space radiation (e.g., plant seeds, insect eggs, etc.) can be sandwiched between layers of nuclear track detectors. These experimental packages can be sealed and flown outside the space station for extended periods of time, then returned to Earth for analysis. The returned specimens will provide measurements of radiation outside the spacecraft. Such information is necessary to assure safe EVAs. This experiment will require minimal space and crew time.
4. **APPROACH:**
 - A. Number/Type Specimens: Various plant seeds, small insect eggs, etc.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Measure amount of radiation during extended duration EVA.
Postflight: Read dosimeters.
 - C. Sample Analysis:
In-flight: None.
Postflight: Examine specimens.
 - D. Experiment Controls:
In-flight: If a safe haven is provided on the space station, then a "Biostack" will be placed there. (It will provide a very close approximation to zero radiation.)
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Radiation measurement devices.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): Put out and bring in "Biostack" exp - 2 hr.
 - C. Experiment Site: LSRF: Attached Payload: ☒ Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-C.
 - B. Science Objectives: RA-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Radiobiology of Very High Energy "Hadronic" Effects and Electromagnetic "Cascades."
2. **PURPOSE/HYPOTHESIS:** Radiobiology of very high energy "hadronic" effects and electromagnetic "cascades."
3. **PROGRAM RATIONALE/JUSTIFICATION:** Galactic cosmic rays have particles with energies many orders of magnitude greater than those available at the most powerful accelerator. The radiobiological effects of "high-energy hadronic events" and "electromagnetic cascades" are unknown at the present time.
4. **APPROACH:**
 - A. Number/Type Specimens: Various plant seeds, insect eggs, etc.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Assess the frequency of such events using stacks of nuclear "Biostack"-type experiments to assess possible radiation hazard.
Postflight: Read dosimeter, conduct growth experiments on specimens.
 - C. Sample Analysis:
In-flight: None.
Postflight: Examine specimens.
 - D. Experiment Controls:
In-flight: None.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Dosimeter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: Attached Payload: ☒ Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-D.
 - B. Science Objectives: RA-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Space Radiation on the Retina.
2. **PURPOSE/HYPOTHESIS:** Measure retinal damage. Extend ground-based experiments with dogs, etc.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Cosmic rays are known to penetrate the retina causing light flashes. Retinas need to be examined for radiation damage. (There is a possible comparison with terrestrial experiments on Rhesus monkeys conducted by USAF/NASA.)
4. **APPROACH:**
 - A. Number/Type Specimens: As many different exposures as possible collected routinely from piggyback experiments. Primate specimens.
 - B. Measurements/Samples:
Preflight: Noninvasive analysis of retinal damage.
In-flight: None.
Postflight: Animals should be retained after flight at Ames Research Center. Noninvasive eye examinations on routine periodic basis.
 - C. Sample Analysis:
In-flight: Evaluations of retinal damage.
Postflight: Same as in-flight.
 - D. Experiment Controls:
In-flight: All controls on which these experiments will piggyback.
Ground-based: All animals should be kept at Ames Research Center.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Passive dosimeter; active dosimeter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 0 hr.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-E.
 - B. Science Objectives: RA-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Possible Cataract Formation/Hazard During Spaceflight.
2. **PURPOSE/HYPOTHESIS:** Measure cataract formation in primates. Cataracts may form that are caused by the space station radiation. Confirm and extend ground-based studies (NASA and DOD).
3. **PROGRAM RATIONALE/JUSTIFICATION:** Animals will be studied on a long-term, noninvasive basis after return to Earth. The experiments will piggyback with others to achieve maximum use of animals. Rodents should not be used for these experiments because they are likely to give spuriously high responses. Comparison with terrestrial lifespan study on Rhesus monkeys conducted by USAF/NASA.
4. **APPROACH:**
 - A. Number/Type Specimens: Primates. Will be done with animals used by others.
 - B. Measurements/Samples:
Preflight: Examine animals for lenticular anomalies.
In-flight: None.
Postflight: Animals should be maintained after flight at Ames Research Center. Evaluation every 3 mo for as long as possible.
 - C. Sample Analysis:
In-flight: Grade eyes for cataract formation.
Postflight: Routine examination of animals postflight.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Same number as in-flight (from different piggyback experiments).
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Active dosimeter; passive dosimeter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 0 hr.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-F.
 - B. Science Objectives: RA-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effects of Space Radiation on Hair Follicles.
2. **PURPOSE/HYPOTHESIS:** To measure localized greying of hair due to high-energy impacts with hair follicles. Based upon original experiments with high-altitude balloons—see below.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is known from early balloon experiments (Haymaker et al.) that hair greying can occur through high atomic number energy (HZE) radiation. This experiment will lead to possible correlation of high-energy events determined by dosimetry and hence serve as a biological dosimeter.
4. **APPROACH:**
 - A. Number/Type Specimens: Primates or rats (piggyback). (Note: Because hairs turn grey in these experiments, albino rats, etc., cannot be used.)
 - B. Measurements/Samples:
Preflight: None.
In-flight: Record HZE particles/cm², total dose. Must be complemented by dosimetry.
Postflight: Maintain animals at NASA Ames Research Center and conduct routine periodic examinations.
 - C. Sample Analysis:
In-flight: None.
Postflight: Examine specimens.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Same number as flight—will use controls for experiments on which this experiment will piggyback.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Active and passive dosimeters.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-G.
 - B. Science Objectives: RA-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Radiation Damage to Stem Cells of Skin.
2. **PURPOSE/HYPOTHESIS:** There can be damage to the stem cell population in the skin by high-energy radiation accompanying solar flares. Animals should be returned to the space station for a second tour to determine effects of repeated exposure. We should confirm and extend current ground-based experiments with the Rhesus monkey and rabbit.
3. **PROGRAM RATIONALE/JUSTIFICATION:** High atomic number energy (HZE) particles, protons, etc., can damage the stem cells and cause mutations and death. Examinations of Rhesus monkeys irradiated with protons have shown such damage in ground-based studies.
4. **APPROACH:**
 - A. Number/Type Specimens: Primates. Collect as many as possible—Rhesus monkey preferred—from experiments upon which this experiment will piggyback.
 - B. Measurements/Samples:
Preflight: Skin biopsies.
In-flight: None.
Postflight: Skin biopsies.
 - C. Sample Analysis:
In-flight: None.
Postflight: Skin stem cell analysis. Dosimetry only.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Same number as in-flight; use animals from experiments on which this experiment will piggyback. All animals should be maintained at NASA Ames Research Center.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Active and passive dosimeters.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 0 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-H.
 - B. Science Objectives: RA-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Space Radiation on Spermatogenesis and Intestinal Villi.
2. **PURPOSE/HYPOTHESIS:** To quantitate the response of the testes to the radiation environment on the space station and determine whether postflight recovery occurs. The biological response of this system will be correlated with the on-board dosimeters. Small intestine samples will be taken from the same animals.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Little is known about the long-term response to low-dose cosmic radiation, especially on tissue flown in space. We have established that testes are very sensitive to less than 0.5 rad of heavy ions. The genetic pool going into space is becoming larger and data on the reproductive system needs to be generated. Ground-based studies have already been done to back up flight experiment. Long-term response/recovery needs to be established.
4. **APPROACH:**
 - A. Number/Type Specimens: 36 (minimum) (6/group, 6 groups) male rats.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Sacrifice six rats each and take tissue samples at 3, 30, 60, and 90 days.
Removal and fixation of testes and small intestine.
Postflight: Take recovery tissue samples from remaining 12 rats on TBD schedule. As in-flight and then quantitation of spermatogonial cell loss and dosimeter readings of all the tissues.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: If centrifuge is available, then centrifuge 6 of the 12 remaining rats to remove weightlessness as a factor.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Special fixative for tissues prepared for electron microscopy.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 min/sample collection and four collections in 90 days = 48 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-I.
 - B. Science Objectives: RA-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Space Environment on Murine Hematopoietic Stem Cells.
2. **PURPOSE/HYPOTHESIS:** We hypothesize that the space environment produces physiologically-endocrinologically-mediated stress that alters mitotic activity in proliferative tissue. The altered proliferative status changes tissue radiation sensitivity and repair capacity and will influence early and late responses to low doses of ionizing radiation.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Physiological stress in the space environment triggers regulatory systems and produces proliferative alterations in those tissues that normally undergo mitotic activity. Interactions between the space environment, proliferative status, and ionizing radiation must be evaluated, because ground-based experimentation does not consider these as issues which are expected to influence radiation risks in space. Susceptibility to or expression of late effects of radiation, viz. mutations, cancer, and cataracts, may also be influenced by proliferative status of cell populations at risk. Susceptibility to radiation injury in the hematopoietic system is expected to be influenced by the level of stem cell mitotic activity. The first step is to measure how the number of cells in the mitotic cycle and cycle time are influenced by the space environment. Murine hematopoietic stem cells (CFU-S) provide a suitable and relevant model system.
4. **APPROACH:**
 - A. Number/Type Specimens: 100 mice.
 - B. Measurements/Samples:

Preflight: Measure femur and spleen content of hematopoietic stem cells (CFU-S) and their proliferative status. Measure blood levels of various hormones (erythropoietin, ACTH, prolactin and thyroid).

In-flight: None.

Postflight: Same as preflight.
 - C. Sample Analysis:

In-flight: None.

Postflight: Hormone and radioimmune assay receptor assays and standard methods will be used for measurements of CFU-S content of proliferation.
 - D. Experiment Controls:

In-flight: None.

Ground-based: Same as in-flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 22.5 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

Radiobiology

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-J.
 - B. Science Objectives: RA-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Refinement of Radiation Dosimetry.
2. **PURPOSE/HYPOTHESIS:** Develop new passive and active dosimetry techniques for radiation measurement of radiobiological experiments. Develop inexpensive, quick readout (on-board) techniques for assessment of space radiation exposure; total dose exposure should be monitored as missions progress.
3. **PROGRAM RATIONALE/JUSTIFICATION:** A variety of different types of space station radiobiological requirements which are being planned will require new approaches to radiation dosimetry.
4. **APPROACH:**
 - A. Number/Type Specimens: None.
 - B. Measurements/Samples: Developed preflight for flight.
 - C. Sample Analysis: Assessment of dosimeter performance and comparison with standard dosimeters.
 - D. Experiment Controls: Standard dosimeters run simultaneously.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Active and passive dosimeters. Equipment developed prior to flight then provided for flight.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 min/reading twice/day but more if solar shower = 8 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-K.
 - B. Science Objectives: RA-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Alteration in the Length and Number of Synapses in the CA-1 Area of the Hippocampus.
2. **PURPOSE/HYPOTHESIS:** To quantitatively measure the synapses in the CA-1 area of the hippocampus. The environment interaction (behavior) center is believed to be mainly located in this area. Radiation should reduce the number of synapses and affect behavior.
3. **PROGRAM RATIONALE/JUSTIFICATION:** See # 2. Ground-based studies have already been done to justify experiment. Radiation affects synapses and behavior.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 rats/group. Two groups if centrifuge is on board.
 - B. Measurements/Samples:
Preflight: Establishment of preflight quantitation of synapses and behavior.
In-flight: Perfusion of animal prior to Earth return, close to day 90.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Quantitation of changes with electron microscopy after behavior tests are complete.
 - D. Experiment Controls:
In-flight: Controls on centrifuge if a centrifuge is available.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Electron microscope fixative.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 3.5 hr/group. Two groups if centrifuge is on board = 7 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Radiobiology RA-L.
 - B. Science Objectives: RA-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): The Response of the Lungs to Cosmic Radiation.
2. **PURPOSE/HYPOTHESIS:** High atomic number energy (HZE) particles may induce pulmonary fibrosis and pneumonitis as does X-irradiation.
3. **PROGRAM RATIONALE/JUSTIFICATION:** A dose of 15 rem is estimated for each 90-day stay in the space station. Astronauts will make multiple trips.
4. **APPROACH:**
 - A. Number/Type Specimens: 20 minimum, 60 optimal mice (or rats).
 - B. Measurements/Samples:
Preflight: None.
In-flight: None.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Morphological analysis with light and electron microscopy.
 - D. Experiment Controls:
In-flight: None, if 20 mice are flown. Twenty if 60 mice are flown and if radiation shelter is on the space station.
Ground-based: Equal number to flight animals.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): Load, unload only if 20 mice. Same on centrifuge if more mice are flown—4 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

RADIOBIOLOGY HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE										
		RA A	RA B	RA C	RA D	RA E	RA F	RA G	RA H	RA I	RA J	RA K
Crew time (hr/90 day)		3	2	2	0	0	1	0	48	23	8	7
Item												
Animal perfusion kit	1											1
BIOSTACK radiation detector	2		1	1								
Cage cleaner	8				1	1	1	1	1	1		1
Fixation kit	2								1			1
Freezer (-20° C)	1											1
G control centrifuge (5')	3							1	1			1
Guillotine	2								1			1
Hand wash facility	8				1	1	1	1	1	1		1
Multi-purpose work bench	7				1	1	1	1	1	1		1
Radiation dosimeter (active)	10	1	1		1	1	1	1	1	1	1	
Radiation dosimeter (passive)	10	1	1		1	1	1	1	1	1	1	
Rhesus monkey food	3				1	1		1				
Rhesus monkey habitat	3				1	1		1				
Rhesus monkey water	3				1	1		1				
Rodent food	5						1		1	1		1
Rodent module	5						1		1	1		1
Rodent water	5						1		1	1		1
Surgery/dissection kit	1								1			
Trash compactor	8				1	1	1	1	1	1		1

N. REPRODUCTION AND DEVELOPMENT

RATIONALE FOR REPRODUCTION AND DEVELOPMENT EXPERIMENTS ON THE SPACE STATION

PRIORITIZED SCIENCE OBJECTIVES FOR REPRODUCTION AND DEVELOPMENT

REPRODUCTION AND DEVELOPMENT EXPERIMENT TITLES

REPRODUCTION AND DEVELOPMENT EXPERIMENT DESCRIPTIONS

REPRODUCTION AND DEVELOPMENT EXPERIMENT HARDWARE AND CREW-TIME REQUIREMENTS

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Reproduction and Development

RATIONALE FOR REPRODUCTION AND DEVELOPMENT EXPERIMENTS ON THE SPACE STATION

The entire evolutionary history of life on Earth has occurred under the omnipresent influence of gravitational force. The basic biological importance of gravity is indicated by the prevalence and diversity of gravity-detection mechanisms in plants and animals. All classes of animals (invertebrates, amphibians, avians, mammals) appear to be affected by gravity during their reproduction and development.

As humans move into space, numerous new questions become both possible and necessary to answer. Can terrestrial life reproduce and develop in microgravity? Do multiple generations retain their "terrestrial integrity" in the absence of constant, normal gravity? Does prolonged exposure to microgravity affect reproduction or development upon return to 1 g? Reproduction and development are the life-cycle phases most likely to reveal the influence of microgravity and provide insights into the means of ameliorating deleterious effects.

Space station will provide the first opportunity to conduct somatic (within a lifetime) and transgenerational (between descendants) studies of space-adapted organisms. Various species will be used to exploit their unique biological characteristics for satisfying multiple science objectives. It is proposed that mammals, birds, amphibia, and insects be studied through complete "egg-to-egg" life cycles, including mating, gestation, and postnatal development.

A two-stage approach for this discipline is proposed. The initial studies should be designed to provide a broad database, most likely to reveal major space-related phenomena of developmental significance. By monitoring developmental parameters on multiple levels, many questions can be simultaneously answered related to issues of basic health, including low-level chronic radiation effects, effects on reproduction, auto-immune responses, and determination of the thresholds for underlying mechanisms. Second, this normative database should be extended with studies of maturation, aging, readaptation to the Earth environment, and tissue regeneration associated with wound-healing.

From such space station studies we expect to gain fundamental insights into reproduction and development which will illuminate the adaptive functions of living systems in the Earth environment and contribute to the health and welfare of humans exposed to space conditions for increasingly long periods. These studies will also provide specimens, models, baseline data, and facilities for commercial biotechnology ventures.

The importance of research in reproduction and development is matched by the timeliness of recent advances in the supporting sciences including genetic engineering, immunology, gene expression, embryology, endocrinology, evolution, behavior, and the neurosciences. These fields will provide technical, theoretical, and methodological support for innovative space enterprises.

PRIORITIZED SCIENCE OBJECTIVES FOR REPRODUCTION AND DEVELOPMENT

- R/D-1 Study complete mammalian life cycle in spaceflight to determine effects on development using space-generated ova and sperm. If development is affected, perform sequential analysis to diagnose and attempt to reverse the defect. (Red Book-1, 2, 4, 12)
Experiments: R/D-A, B, C, D, E, F, G, H, EE
- R/D-2 Study complete avian life cycle using bipedal organisms free of indirect maternal influence to evaluate development of bone, organogenesis, vestibular mechanisms, and behavior. (Red Book-6, 7)
Experiments: R/D-I, J, K, L
- R/D-3 Study complete amphibian life cycle using specimens with known gravity-sensitive eggs and evaluate metamorphosis and direct development. (Red Book- 4, 11)
Experiments: R/D-M, N, O
- R/D-4 Multigeneration studies on insects and other invertebrates with large numbers per generation and established genetic lines to evaluate muscle maturation, exoskeleton, mutations, embryo viability, and fecundity. (Red Book-8, 9, 10)
Experiments: R/D-P, Q, R, S, T
- R/D-5 Study gravitational thresholds of developmental mechanisms using on-board variable-gravity centrifuge. Define gravity-sensing mechanisms and effective countermeasures for adverse effects of long-duration microgravity. (Red Book-3)
Experiments: R/D-U
- R/D-6 Study gravitational influences on maturation and aging and role in life cycle regulation. Mutagenesis and tumorigenesis may be special problems in this area. (Red Book-2, 9)
Experiments: R/D-V, W, X, Y, Z, FF
- R/D-7 Study readaptation to 1 g after development in microgravity in various specimens. (Red Book-5, 7, 10)
Experiments: R/D-AA
- R/D-8 Wound-healing and regeneration studies during long-duration spaceflight in various specimens. (Red Book-None, see JSC Experiments)
Experiments: R/D-BB, CC, DD

REPRODUCTION AND DEVELOPMENT EXPERIMENT TITLES

Code	Title	Objective
R/D-A	Multiple-Generation Studies of Mammals in Space	R/D-1
R/D-B	Mammalian Pregnancy, Birth, and Maturation	R/D-1
R/D-C	Production of Second-Generation Mammals Conceived and Matured in Spaceflight	R/D-1
R/D-D	Reproduction Subsequent to Space Exposure	R/D-1
R/D-E	Morphological Evaluation of Mammals Gestated in Microgravity	R/D-1
R/D-F	Cause(s) of Reproductive Failure in Mammals Participating in Experiment RD-A	R/D-1
R/D-G	Mother-Offspring Interactions During Lactation Cycle	R/D-1
R/D-H	Mammalian Postnatal Maturation in Microgravity	R/D-1
R/D-I	Multigenerational Production of Avian Species	R/D-2
R/D-J	Effect of Spaceflight Adaptation on Avian Reproduction	R/D-2
R/D-K	Effect of Terrestrial Readaptation on Avian Reproduction	R/D-2
R/D-L	Effect of Microgravity and Various Levels of Gravity on the Development of the Chick Embryo Otolithic Organs	R/D-2
R/D-M	Complete Life Cycle of Amphibia in Microgravity	R/D-3
R/D-N	Space-Rearing of Amphibia—Effects on Subsequent Earth-Reared Generations	R/D-3
R/D-O	Postflight Fecundity of Amphibia	R/D-3
R/D-P	Multigeneration Reproduction in Insects	R/D-4
R/D-Q	Fecundity of Insects in Space	R/D-4
R/D-R	Mating Behavior of Mutant Insects in Space	R/D-4
R/D-S	Muscle Maturation of Insects in Space	R/D-4
R/D-T	Jellyfish Reproduction and Development in Space	R/D-4
R/D-U	Gravitational Thresholds of Developmental Mechanisms	R/D-5
R/D-V	Heat Shock Proteins in Insects in Space	R/D-6

Reproduction and Development

R/D-W	Effect of Spaceflight on Aging of Insects	R/D-6
R/D-X	Effect of Spaceflight on Aging of Mutant Insects	R/D-6
R/D-Y	Rate of Mammalian Maturation Determined by Timing of Epiphyseal Plate Closure	R/D-6
R/D-Z	Mutational Load Accretion over Multigenerations in Space	R/D-6
R/D-AA	Time Course and Quality of Readaptation to 1 g	R/D-7
R/D-BB	Effect of Microgravity on Wound Healing	R/D-8
R/D-CC	Effect of Spaceflight on Bone Healing	R/D-8
R/D-DD	Limb Regeneration Following Microgravity Adaptation	R/D-8
R/D-EE	Study of Mating Behavior and Embryonic Development in the Mouse in Microgravity	R/D-1
R/D-FF	Gerontological Physiology in Microgravity	R/D-6

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-A.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Multiple-Generation Studies of Mammals in Space.
 2. **PURPOSE/HYPOTHESIS:** To determine the feasibility of producing successive generations of rodents in space.
 3. **PROGRAM RATIONALE/JUSTIFICATION:** The mammalian life cycle (reproduction and development) evolved in the presence of gravity. Can the mammalian life cycle be expressed in microgravity? Ultimately, space habitation will require unimpaired reproduction and development. Human safety after space exposure is an ethical necessity. Science and commercial interests will require vivaria and space-adapted animals. Basic biological questions can be posed and answered.
 4. **APPROACH:**
 - A. Number/Type Specimens: 10 female, 4 male each rats and mice.
 - B. Measurements/Samples:
Preflight: Reproductive rates and fecundity (proven breeders).
In-flight: Weights at intervals, continuous video, and food and water intake. Cull litters soon after birth, and fix culls.
Postflight: Weights, behavior, allometry, readaption, and breeding.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of data collected in-flight.
 - D. Experiment Controls:
In-flight: None—centrifuge controls are not essential at this stage.
Ground-based: Littermate vivarium and synchronous controls. (The sibling matings on Earth—siblings of space rodents—are the critical controls.)
 5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items):
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:
- Note: Time course: 180 days (Multiple 90-day windows)

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-B.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Mammalian Pregnancy, Birth, and Maturation.
2. **PURPOSE/HYPOTHESIS:** To initiate developmental biology of mammals in space by flying terrestrially impregnated rodents and allowing them to complete gestation and give birth in space.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Space station vivarium requires thorough understanding of all phases of development. This initial study will bypass potential problems of mating at 0 g and initiate critical life-cycle studies in rodents.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 rats and 6 mice.
 - B. Measurements/Samples:
Preflight: Reproduction (mass, counts, evaluations).
In-flight: Mass, observations.
Postflight: N/A.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Synchronous controls.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-C.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Production of Second-Generation Mammals Conceived and Matured in Spaceflight.
2. **PURPOSE/HYPOTHESIS:** Demonstrate capability of mammalian species to execute complete life cycle by producing a second generation in spaceflight.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This will be the first test of mammalian ova differentiated in space. This will serve as the initial test of gravity sensitivity of earliest pattern specification and organization in mammalian germinal material (during first trimester of gestation of Reproduction and Development Experiment A).
4. **APPROACH:**
 - A. Number/Type Specimens: 8 female, 3 male mice and rats. F₁ specimens derived from Reproduction and Development Experiment A.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Maternal weights, litter observations, and litter culls.
Postflight: Morphology of newborn litter culls, ground breeding of both F₁ and F₂ generations.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Synchronous controls derived from returned material (Reproduction and Development Experiment A).
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Development facility.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-D.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Reproduction Subsequent to Space Exposure.
2. **PURPOSE/HYPOTHESIS:** To determine the reproductive capability of male and female mammals (rodents) that have sustained long-term exposure (90 days) to space. This experiment will test subsequent effects of space on reproduction and serve as a within-subject comparison control for breeding capability in space.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Habitation of space has profound implications for human welfare subsequent to space exposure. In addition, it is essential to carefully compare reproductive sequences in space and on Earth.
4. **APPROACH:**
 - A. Number/Type Specimens: 10 pairs of each (original parents 28), 10 pairs of F₁, F₃, F₇, F₉, F₁₀ progeny, rats and mice.
 - B. Measurements/Samples:
Related to Reproduction and Development Experiment R/D-A; same animals returned to Earth for postflight test.
 - C. Sample Analysis:
In-flight: Data from Reproduction and Development Experiment R/D-A.
Postflight: Reproductive capacity.
 - D. Experiment Controls:
Built-in control for Reproduction and Development Experiment R/D-A.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): None.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-E.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Morphological Evaluation of Mammals Gestated in Microgravity.
2. **PURPOSE/HYPOTHESIS:** Provide morphological evaluation of newborn mammals conceived and gestated in microgravity. Five generations will be studied: F₁, F₃, F₅, F₇, and F₉.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Comparative analyses of neuroanatomical, musculoskeletal, and cardiovascular system development. These specimens are derived from the multigeneration study.
4. **APPROACH:**
 - A. Number/Type Specimens: 25 each (5 per generation) rats and mice.
 - B. Measurements/Samples:
Preflight: N/A.
In-flight: Sacrifice, fixation, blood samples, storage, and return to Earth.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Comparative microscopic analyses.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Synchronous, vivarium.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Fixative kits and specimen transporter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 6 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

Note: As part of multigenerational study, this experiment will occur at termination of each 90-day leg of project.

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-F.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Cause(s) of Reproductive Failure in Mammals Participating in Experiment R/D-A.
2. **PURPOSE/HYPOTHESIS:** Identify the process(es) that is/are sensitive to spaceflight conditions and which does/do not proceed normally in mammals which have been flown in space.
3. **PROGRAM RATIONALE/JUSTIFICATION:** If reproductive failure is encountered during experiment R/D-A (multigeneration studies of animals), this experiment is designed to determine whether the following developmental endpoints occur normally:
 - (a) preimplantation development/blastocyst stage,
 - (b) implantation/decidual reaction,
 - (c) placentation/vascularization, choriogonadotropin and progesterone production,
 - (d) embryogenesis/organ formation, and
 - (e) development to term/day 19 of gestation.
4. **APPROACH:**
 - A. Number/Type Specimens: 25 mice, outbred females, (*Mus musculus*): hormonally primed and mated on the ground and launched on day 1 of pregnancy.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Sacrifice five females for each of five time points to study developmental endpoint. NOTE: Detailed experimental design and protocol are available on file.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Female littermate controls participating in a parallel experiment in a vivarium with the same lighting conditions and temperature as the in-flight vivarium.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vivarium, dissecting microscopes, facilities for fixation, and refrigerator for storing fixed specimens.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-G.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Mother-Offspring Interactions During Lactation Cycle.
2. **PURPOSE/HYPOTHESIS:** To evaluate quantity and quality of maternal care provided to offspring and its coordination with stimuli arising from litter (rat/mouse).
3. **PROGRAM RATIONALE/JUSTIFICATION:** In order to interpret data on offspring development, it is necessary to know about maternal support (contact stimulation, lactation, and nest hygiene). Similarly, to assess maternal behavior, it is important to evaluate stimulation arising from offspring.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 each (plus litters) rats and mice (lactating).
 - B. Measurements/Samples:
Preflight: Baseline.
In-flight: Automated/observational (video) data collection and automated recording of maternal feeding and drinking. Video and automatic monitoring of nest attendance, nursing, feeding, circadian rhythmicity, and offspring ultrasounds. Very desirable to have ability to download data to Earth for monitoring by investigator.
Postflight: Baselines useful.
 - C. Sample Analysis:
In-flight: Analysis of mother-offspring interaction.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Vivarium and synchronous controls.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Time-lapse video, automated feeders, and water supply.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Reproduction and Development

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-H.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Mammalian Postnatal Maturation in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine rate and quality of postnatal development in mammals born in space.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Formative processes of development may use gravitational forces for organizing or sculpting morphogenics and functional development. This experiment is designed to support analysis of "feasibility" studies and set stage for specific detailed investigations.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 each rats and mice, (8 pups per litter x 6 litters = 48).
 - B. Measurements/Samples:
Preflight: N/A.
In-flight: Inspection of developmental landmarks (until vaginal opening), mass, and video data. Collect and fix culls, time-series of sacrifices to provide for allometry (see also bone and muscle).
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Mass measurement for infants from 3-50 grams.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 15 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-I.
 - B. Science Objectives: R/D-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Multigenerational Production of Avian Species.
2. **PURPOSE/HYPOTHESIS:** Determine the capability of avian species to carry out complete life cycle in microgravity, and determine the establishment of correct anteroposterior embryo axis.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Rotation of avian egg during early embryogenesis is potentially gravity-sensitive. Study nonplacental development and life cycles in avian model.
4. **APPROACH:**
 - A. Number/Type Specimens: 8 female quail, *Coturnix japonica*, frozen sperm for artificial insemination.
 - B. Measurements/Samples:

Preflight: Install birds in avian holding facility for 2-wk adaptation.

In-flight: Wk 1: artificially inseminate with sperm from storage; collect and store fertile eggs at 4° C for 1 wk. Wk 2: incubate eggs at 37° C, 65% RH to hatch (~ 17d). Sacrifice schedule of embryos and developmental morphology are TBD. Wk 5: harvest hatchlings and house in "hatchling" facility. Segregate by sex. Sample TBD. Return samples to Earth. Retain eight females for F₂ generation.

Postflight: Wk 1: artificially inseminate eight F₁ females to test viability of ova formed in-flight.
 - C. Sample Analysis:

In-flight: None.

Postflight: Analysis of samples collected in-flight.
 - D. Experiment Controls:

In-flight: 1-g centrifuge.

Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Avian holding facility, "hatchling" facilities, and avian transporter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): TBD.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-J.
 - B. Science Objectives: R/D-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight Adaptation on Avian Reproduction.
2. **PURPOSE/HYPOTHESIS:** Determine effect of space adaptation on reproductive process in nonmammalian, bipedal vertebrate.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Space-adapted quail returned from R/D-I will be ground bred to determine long-term effects of space adaptation on avian reproduction.
4. **APPROACH:**
 - A. Number/Type Specimens: 8 female quail *Coturnix japonica* derived from R/D-I original birds.
 - B. Measurements/Samples:
Preflight: N/A.
In-flight: None.
Postflight: Breeding.
 - C. Sample Analysis:
In-flight: None.
Postflight: Evaluation.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Hatched.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Avian transporter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 0 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-K.
 - B. Science Objectives: R/D-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Terrestrial Readaptation on Avian Reproduction.
2. **PURPOSE/HYPOTHESIS:** Provide Earth-based controls derived from R/D-I as F₁ generation.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Readaptation of F₁ quail conceived and matured in space. These are matched to continuing space-based population.
4. **APPROACH:**
 - A. Number/Type Specimens: TBD number *Coturnix japonica* , F₁ derived from R/D-I .
 - B. Measurements/Samples: Ground-based control for F₁ to F₂ space experiment.
 - C. Sample Analysis: N/A.
 - D. Experiment Controls: N/A.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Avian transporter.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 0 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-L.
 - B. Science Objectives: R/D-2.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): (A) RD2b/Effect of Microgravity and Various Levels of Gravity on the Development of the Chick Embryo Otolithic Organs.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of microgravity and various levels of gravity on the development of the chick embryo otolithic organs.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This study will increase our understanding of the extent to which gravity influences the development of gravity receptors of the inner ear. The study will specifically determine to what extent microgravity affects (a) secretion of the otolithic membrane, (b) production of statoconia, and (c) calcification of statoconia during critical periods of development.
4. **APPROACH:**
 - A. Number/Type Specimens: 24 chicken eggs.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Eggs will be incubated on ground and/or in space and then specimens will be collected either in space or on ground, fixed, and processed for electron microscopy observations.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of samples.
 - D. Experiment Controls:
In-flight: 1 g and other gravity levels (0.1 to 1 g) to study possible threshold effect.
Ground-based: Parallel to flight specimens.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Egg incubator.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 20 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/Expt. Code: Reproduction and Development R/D-M.
 - B. Science Objectives: R/D-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Complete Life Cycle of Amphibia in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine whether multiple generations of amphibia can be obtained in microgravity. The amphibian egg orients to gravity when fertilized. Based on the results of experiments on the Space Shuttle, can subsequent stages of development, e.g., metamorphosis (transition from an aquatic to a terrestrial environment), occur in microgravity? Does organogenesis occur normally in an aquatic versus terrestrial animal, e.g., musculoskeletal system, nervous system, cardiovascular system, etc.?
3. **PROGRAM RATIONALE/JUSTIFICATION:** NASA's program in developmental biology attempts to understand the role of gravity and the lack thereof on all aspects of reproduction and development. Amphibian eggs display an unequivocal gravity response (egg rotation) at 1 g, so gravity effects at less than 1 g can be expected.
4. **APPROACH:**
 - A. Number/Type Specimens: Two breeding pairs of 4 species of short life-cycle amphibia: one aquatic species; two terrestrial species (one a direct developer—nonmetamorphosis; one an indirect developer—metamorphosis); one burrowing species (apoda-bear live young).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Inject female and males to induce ovulation and breeding; place 200 embryos at 1 g and 200 at 0 g; fix 10 specimens weekly.
Postflight: Animal behavior at 1 g and reproductive ability.
 - C. Sample Analysis:
In-flight: Video analysis of mating behavior.
Postflight: Histology.
 - D. Experiment Controls:
In-flight: 1-g centrifuge controls.
Ground-based: Parallel ground control to compare any adverse reactions of spaceflight exposure (increase in mutation rate).
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items):
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-N.
 - B. Science Objectives: R/D-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Space-Rearing of Amphibia—Effects on Subsequent Earth-Reared Generations.
2. **PURPOSE/HYPOTHESIS:** To determine whether frogs (F₁) conceived and reared in microgravity are fertile and yield normal progeny (F₂) in an ongoing microgravity environment and when returned to 1 g.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Germ plasm on the inner cortex of the egg moves in response to the gravity-induced intracellular cytoplasmic shifts. Sterile progeny could result.
4. **APPROACH:**
 - A. Number/Type Specimens: Four breeding pairs of spaceflight-derived frogs (*Xenopus laevis* or frog with shorter life cycle).
 - B. Measurements/Samples:

Preflight: N/A.

In-flight: Induce ovulation with hormone, fertilize eggs in vitro, and raise embryos to maturity. Fix specimens at weekly intervals for postflight analysis.

Postflight: Return live F₁ breeding pairs to Earth and repeat in-flight studies.
 - C. Sample Analysis:

In-flight: Determine fertilization success, percent hatching normally, percent metamorphosing normally, and percent reaching maturity.

Postflight: Histology.
 - D. Experiment Controls:

In-flight: 1-g centrifuge.

Ground-based: Parallel breeding colony F₁ and F₂.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items):
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-O.
 - B. Science Objectives: R/D-3.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Postflight Fecundity of Amphibia.
2. **PURPOSE/HYPOTHESIS:** Determine whether adult female frogs that have been exposed to spaceflight for several weeks and have spawned in microgravity will ovulate and produce normal ova at 1 g.
3. **PROGRAM RATIONALE/JUSTIFICATION:** After several weeks in space the cumulative effects of microgravity, radiation, and other stresses of spaceflight may detrimentally affect the postflight reproductive capacity of amphibia.
4. **APPROACH:**
 - A. Number/Type Specimens: 6 female frogs (*Xenopus* or other).
 - B. Measurements/Samples:
Preflight: Spawning history of the animals.
In-flight: Fertilization quality and quantity of eggs produced.
Postflight: Induce ovulation, fertilize, and examine progeny for normal embryogenesis and maturation.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: 1-g centrifuge.
Ground-based: Repeat fertilization test with animals held under normal lab conditions on Earth.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items):
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: poss Platform: poss

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-P.
 - B. Science Objectives: R/D-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Multigeneration Reproduction in Insects.
2. **PURPOSE/HYPOTHESIS:** The purpose of this experiment is to determine whether multiple generations can successfully be obtained in microgravity and to compare late-generation insects with late-generation ground controls.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Need to determine whether multigenerations can be obtained in microgravity and whether animals produced under these conditions experience any selection pressures (e.g., male, female) and whether late-generation organisms are normal compared to ground-based insects.
4. **APPROACH:**
 - A. Number/Type Specimens: Start with 20 male and 30 female fruit flies (*Drosophila melanogaster*).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Insects will be allowed to reproduce through multiple generations for at least 90 days (8 generations). This can be accomplished without crew involvement except at the end of the flight period when the "module" containing the last generation of insects and their prospective offspring will be sent to Earth for postflight analysis.
Postflight: Examine body weights, sex ratios, percent of eggs that develop, lifespan, and other physiological and biochemical parameters designed to determine "normalcy" of the last generation of insects from microgravity.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Same as in-flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Special platform module (pressurized, temperature regulation, light, etc.) for insects.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 1 hr.
 - C. Experiment Site: LSRF: Attached Payload: Platform: ✓

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-Q.
 - B. Science Objectives: R/D-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Fecundity of Insects in Space.
2. **PURPOSE/HYPOTHESIS:** Weightlessness may affect the fecundity of female insects and the viability of embryos.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Previous work in altered gravity suggests that these particular parameters may be affected by the stresses of the spaceflight environment.
4. **APPROACH:**
 - A. Number/Type Specimens: 20 male, 30 female fruit flies (*Drosophila melanogaster*).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Record number of eggs deposited per female. Determine viability. Observe behavior for changes in postural control.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls as per flight .
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: poss Platform: poss

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-R.
 - B. Science Objectives: R/D-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Mating Behavior of Mutant Insects in Space.
2. **PURPOSE/HYPOTHESIS:** It is expected that adaptation to microgravity is manifested in less disturbed flying behavior and more efficient mating ability. Presumably such adaptation is the result of "learning."
3. **PROGRAM RATIONALE/JUSTIFICATION:** This hypothesis can be tested by comparing the adaptiveness of normal wild strains and learning-deficient mutants, e.g., dunce.
4. **APPROACH:**
 - A. Number/Type Specimens: 20 males, 30 females, wild; 20 male, 30 female dunce fruit flies (*Drosophila melanogaster*) (pupae).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Number of matings will be monitored by written record. Video monitor of mating behavior.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Groundbased: Controls as per flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): None.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

NOTE: This time estimate may be very modest, and this experiment may require specialized videographic capability to save crew time.

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-S.
 - B. Science Objectives: R/D-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Muscle Maturation of Insects in Space.
2. **PURPOSE/HYPOTHESIS:** Maturation of the insect flight muscle may be altered in microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Uncoordinated and altered flying activity of insects raised in microgravity is expected to inhibit the normal 1-g maturation of the insect flight muscle.
4. **APPROACH:**
 - A. Number/Type Specimens: 100 male fruit flies (*Drosophila melanogaster*).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Collect insects at different ages from the initial population, homogenize, and prepare for enzyme analysis.
Postflight: None.
 - C. Sample Analysis:
In-flight: Determine activity of marker enzyme, e.g., cytochrome oxidase.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls as per flight insects.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Spectrophotometer.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 10 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-T.
 - B. Science Objectives: R/D-4.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Jellyfish Reproduction and Development in Space.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of long-term exposure to microgravity and various levels of gravity on developing ephyrae which metamorphose from polyps.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This study will help to elucidate the role gravity plays in development, and to discover whether long-term exposure to microgravity will result in behavioral, anatomical, and physiological changes.
4. **APPROACH:**
 - A. Number/Type Specimens: 50 jellyfish.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Some tissue fixed. Some specimens returned live for analysis. Videotaping.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: 0.1-g to 1-g controls.
Ground-based: None.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Sterile media/sterile artificial seawater container/aquarium (self-contained).
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 8 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

Reproduction and Development

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-U.
 - B. Science Objectives: R/D-5.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Gravitational Thresholds of Developmental Mechanisms.
2. **PURPOSE/HYPOTHESIS:** To determine whether gravity serves a functional role for induction, canalization, maintenance, or facilitation of developmental mechanisms, and to establish the threshold of minimal gravitational stimulation required by these developmental mechanisms.
3. **PROGRAM RATIONALE/JUSTIFICATION:** We anticipate that space station research will reveal basic gravity-dependent mechanisms at numerous points in the development of various forms of animal life. Titration of gravity levels sufficient to actuate or modify these mechanisms can be accomplished with a variable-gravity centrifuge.
4. **APPROACH:**
 - A. Number/Type Specimens: Specimen range (species/age) defined by results of experiments R/D-A, B, C, E, H.
 - B. Measurements/Samples: TBD.
 - C. Sample Analysis: TBD.
 - D. Experiment Controls: Variable-gravity centrifuge studies.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Variable-gravity centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 30 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-V.
 - B. Science Objectives: R/D-6.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Heat-Shock Proteins in Insects in Space.
2. **PURPOSE/HYPOTHESIS:** Spaceflight stresses may induce the formation of "heat-shock" proteins or possibly of a new subset of previously undescribed "stress-related" polypeptides.
3. **PROGRAM RATIONALE/JUSTIFICATION:** It is well documented that *Drosophila* respond to a number of environmental stresses by synthesizing a class of polypeptides known as heat-shock proteins. It is expected that spaceflight stress, and in particular microgravity, may induce the expression of these or similar proteins.
4. **APPROACH:**
 - A. Number/Type Specimens: 25 male fruit flies (*Drosophila melanogaster*).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Label insects with radioisotopes (^{14}C -leucine, or ^{35}S -methionine). Homogenize insects in lysis buffer and store for postflight analysis.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Two-dimensional gel electrophoresis and autoradiography.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls as per flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Hand homogenizer and special housing containers for labeling insects.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: \checkmark Attached Payload: poss Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-W.
 - B. Science Objectives: R/D-6.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight on Aging of Insects.
2. **PURPOSE/HYPOTHESIS:** Adult insects will experience accelerated aging in space.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This postulated life shortening in space is based on the fact that insects will use more oxygen (experience increased metabolic rate) because of uncoordinated flight in absence of gravitational clues.
4. **APPROACH:**
 - A. Number/Type Specimens: 200 male fruit flies (*Drosophila melanogaster*).
 - B. Measurements/Samples:
Preflight: None.
In-flight: Record survival data, maintain insects.
Postflight: Analysis of data collected in-flight.
 - C. Sample Analysis:
In-flight: None.
Postflight: None.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls as per flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Special housing containers for insects.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 8 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: poss Platform: poss

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-X.
 - B. Science Objectives: R/D-6.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight on Aging of Mutant Insects.
2. **PURPOSE/HYPOTHESIS:** The previously observed life shortening of insects in microgravity is the result of increased activity (and metabolic rate) due to uncoordinated flight.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The above hypothesis can be tested with the use of mutants which do not fly (vestigial wing, miniature, etc.). It is expected that these mutants will not experience life shortening relative to ground-based controls.
4. **APPROACH:**
 - A. Number/Type Specimens: 400 fruit flies (*Drosophila melanogaster*), 200 wild males, 200 mutants.
 - B. Measurements/Samples:
Preflight: None.
In-flight: Record survival data. Maintain insects.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of data collected in-flight.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls as per flight.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Special housing containers for insects.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 8 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: poss Platform: poss

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-Y.
 - B. Science Objectives: R/D-6.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Rate of Mammalian Maturation Determined by Timing of Epiphyseal Plate Closure.
2. **PURPOSE/HYPOTHESIS:** Determine whether epiphyseal plate closure in space-reared rodents is accelerated, delayed, or unchanged in comparison with ground-based controls.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Obtain essential information on mammalian maturation rates in space by monitoring a normal growth process (epiphyseal plate closure) in rodents.
4. **APPROACH:**
 - A. Number/Type Specimens: 25 male rat pups produced during R/D-A multigenerational breeding cycles. (If R/D-A fails, then obtain male pups from R/D-B and R/D-F).
 - B. Measurements/Samples:

Preflight: N/A.

In-flight: Weigh rats every 2 wk, beginning at age 28 days. Sacrifice 5 rats on postnatal days 70, 84, 98, 112, and 128, and fix for skeletal analysis. In addition, inject tetracycline at two time-points (day 30 and the day preceding the sacrifice).

Postflight: N/A.
 - C. Sample Analysis:

In-flight: None.

Postflight: Growth/maturation will be measured by 1) degree of epiphyseal plate closure of the digits, and 2) distance separating tetracycline-labeled Haversian canal rings.
 - D. Experiment Controls:

In-flight: Parallel experiment with space-derived male rat pups in an on-board centrifuge.

Ground-based: Parallel experiment done with age-matched control male rat pups of same strain as space-derived pups.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Vivarium, refrigerator, centrifuge for rodents, and facilities for fixing rats for skeletal analysis.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-Z.
 - B. Science Objectives: R/D-6.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Mutational Load Accretion over Multigenerations in Space.
2. **PURPOSE/HYPOTHESIS:** Long-term exposure to space may affect rate of mutation in successive generations of mammals. May be seen in tumorigenesis in organs such as blood and eyes, as well as in loss of developmental control.
3. **PROGRAM RATIONALE/JUSTIFICATION:** There is a likelihood that an accumulated dose of radiation will be sufficient to render males aspermatic.
4. **APPROACH:**
 - A. Number/Type Specimens: 20 animals, possibly derived from multigeneration flight colony. May amplify response rate by using inbred strains (e.g., AKR mice).
 - B. Measurements/Samples:
Preflight: Baseline.
In-flight: Sample every x (e.g., = 3) generations. Use animals in intervening generations for other experiments. Subjects go to "natural" death and are assessed.
Postflight: Assess tumorigenesis.
 - C. Sample Analysis:
In-flight: TBD.
Postflight: TBD.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Controls as per flight animals.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Dosimeter, breeding facility and holding cages, and fixative in event of death.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 5 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-AA.
 - B. Science Objectives: R/D-7.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Time Course and Quality of Readaptation to 1 g.
2. **PURPOSE/HYPOTHESIS:** To elucidate capacity of animals to adapt to introduction to gravity, particularly during phases of early development. Gravity-sensitive mechanisms should be revealed.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Animals will be produced in excess of available facilities on the space station. They represent a valuable scientific resource for studying developmental plasticity and gravitational adaptation. Some animals will be returned to Earth, and some will be placed on the on-board, variable-gravity centrifuge.
4. **APPROACH:**
 - A. Number/Type Specimens: Weanling and juvenile-aged rodents born in space, and available for return (live) to Earth.
 - B. Measurements/Samples:
Preflight: N/A.
In-flight: Morphological/allometric, growth, endocrine and behavioral profile, reproductive fitness.
Postflight: Same as in-flight.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of data collected in-flight.
 - D. Experiment Controls: Synchronous controls.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Variable-gravity centrifuge.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 2 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-BB.
 - B. Science Objectives: R/D-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Microgravity on Wound Healing.
2. **PURPOSE/HYPOTHESIS:** Microgravity may alter the rate and quality of the healing processes.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Minimal data on epithelialization and dermal regeneration in space are currently available. The 90-day crew cycle proposed for the space station and the difficulties in unscheduled returns of anyone injured or in surgical interventions of the crew make this area of study a high priority.
4. **APPROACH:**
 - A. Number/Type Specimens: 30 rats, 5 per group (minimum); 6 groups total.
 - B. Measurements/Samples:
Preflight: None.
In-flight: After gingivectomy of maxillary region on flight day 1, take tissue sample from injured and opposite (control) side of mouth at 2 wk intervals from 2-12 wk. Place half of each tissue sample in liquid nitrogen and half in fixative.
Postflight: None.
 - C. Sample Analysis:
In-flight: None.
Postflight: Analysis of samples taken in-flight. Analysis includes biochemical and electron microscopy ultrastructural studies.
 - D. Experiment Controls:
In-flight: Right (uninjured) gingiva of the wounded animal.
Ground-based: 1) Injured on day 1 of the flight (24 hr approx.) 2) Same time intervals as expt. group in space station.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Liquid nitrogen or equivalent.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 10 hr.
 - C. Experiment Site: LSRF: ✓ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-CC.
 - B. Science Objectives: R/D-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Effect of Spaceflight on Bone Healing.
2. **PURPOSE/HYPOTHESIS:** To determine the effects of reduced gravity on fracture repair in young adult and old mice. The rate of healing and bone repair may be unduly prolonged in reduced gravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** Although the fracture repair process is similar at different ages, the rates of repair vary considerably. It is essential to know the effects of reduced gravity on repair of the skeletal system in response to trauma, as humans will be spending extended time in space laboratories and as their physical work and varied tasks expose them to greater dangers.
4. **APPROACH:**
 - A. Type/Number Specimens: 48 BNL short-lived mice—26 and 78 wk old, 48 mice in-flight; 24 mice ground-based. (Available from the investigator's colony.)
 - B. Measurements/Samples:

Preflight: Weekly weight measurements taken.

In-flight: Animals will be acclimated in-flight for 1 wk. Left femur of 20 mice at microgravity and 20 mice at 1 g will be fractured in groups of 4 at day 2, day 7, day 14, 1 mo and 3 mo (less 1 wk for acclimation). Weekly weight measurements taken.

Samples: femora from unilaterally fractured mice and the nonfractured opposite limb. Fixation of femoral samples in neutral buffered formalin. Twenty mice in microgravity—left femur fractured. Twenty mice in 1 g—left femur fractured. (Nonfractured right femora serve as controls.)

Postflight: None.
 - C. Sample Analysis:

In-flight: Histological and TV-image analysis of the course of fracture repair.

Postflight: Analysis of data collected in-flight.
 - D. Experiment Controls:

In-flight: 4 nonfractured at 0 g; 4 nonfractured at 1 g. (Nonfractured right femora serve as controls.)

Ground-based: 20 left-side fractured; 4 nonfractured (following same schedule as for in-flight mice).
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Nembutal anaesthetic for sacrifice, dissecting instruments, and fixing agents.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 19 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-DD.
 - B. Science Objectives: R/D-8.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Limb Regeneration Following Microgravity Adaptation.
2. **PURPOSE/HYPOTHESIS:** Analyze processes of amphibian limb regeneration to determine effects of microgravity adaptation on bone, muscle, and nerve regeneration.
3. **PROGRAM RATIONALE/JUSTIFICATION:** This study of a precisely defined regenerative process involves analyzing physiological responses of vertebrate bone, muscle, and nervous motor integration following full space integration.
4. **APPROACH:**
 - A. Type/Number Specimens: 100 salamanders (*Triturus viridesceus*), two groups of 50 each.
 - B. Measurements/Samples:

Preflight: All group II specimens have surgical amputation of one limb through elbow 1 wk before flight.

In-flight: All group I specimens have surgical amputation of one limb through elbow at flight day 80. Photography of limbs of live salamanders on weekly basis. Sacrifice two animals per group per week; fix and store for postflight morphology.

Postflight: 24 animals per group are returned to Earth for analysis.
 - C. Sample Analysis:

In-flight: None.

Postflight: Morphology, regeneration staging.
 - D. Experiment Controls:

In-flight: Group II animals.

Ground-based: Returned live specimens will undergo subsequent regeneration control limits.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Moist habitat.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 15 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-EE.
 - B. Science Objectives: R/D-1.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): (A)RD1/Study of Mating Behavior and Embryonic Development in the Mouse in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine whether mice can mate in microgravity and to study the in utero development of the conceived animals up to parturition. The hypothesis to be investigated is that microgravity will have an effect on embryogenesis or fetogenesis.
3. **PROGRAM RATIONALE/JUSTIFICATION:** A major question with respect to mammalian development in microgravity is whether microgravity has an effect on the developing embryo or fetus. This experiment should provide critically needed information about whether microgravity actually has an effect. If not, future developmental studies should focus on postnatal development.
4. **APPROACH:**
 - A. Number/Type Specimens: 120 females, 10 males, Swiss-Webster, albino mice, half at 1 g and half in microgravity.
 - B. Measurements/Samples:
 - Preflight: Body mass of test animals.
 - In-flight: Make video record of test animals' mating activities. Body mass of test animals and of developing fetuses to be determined at definite times of gestation. Some pregnant mice sacrificed at different stages of gestation, uteri removed and frozen for postflight examination.
 - Postflight: Body mass of test animals. Examination of frozen uteri. Histological examination of fetuses.
 - C. Sample Analysis:
 - In-flight: None.
 - Postflight: Analysis of data collected from in-flight animals.
 - D. Experiment Controls:
 - In-flight: 1-g centrifuge controls.
 - Ground-based: Controls tested similarly to 0-g test mice.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Small rodent centrifuge (radius can be 2 ft) and infrared camera system to monitor mice during night phase.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 90 hr.
 - C. Experiment Site: LSRF: ☒ Attached Payload: Platform:

1. **EXPERIMENT/SCIENCE OBJECTIVE/REFERENCE:**
 - A. Discipline/ Expt. Code: Reproduction and Development R/D-FF.
 - B. Science Objectives: R/D-6.
 - C. McDAC Expt. Ref. #/Title (orig. or modified): Gerontological Physiology in Microgravity.
2. **PURPOSE/HYPOTHESIS:** To determine physiological alterations during mammalian aging in microgravity.
3. **PROGRAM RATIONALE/JUSTIFICATION:** The normal aging process in mammals will be impacted by the adaptational changes produced by exposure to microgravity. This study requires long-duration, continuous exposure and careful periodic sampling to minimize microgravity disturbances.
4. **APPROACH:**
 - A. Type/Number Specimens: 8 male rodents (rats/mice)—Earth-derived; 8 male rodents (rats/mice)—F₁ derived from R/D-A.
 - B. Measurements/Samples:
Preflight: None.
In-flight: TBD.
Postflight: TBD.
 - C. Sample Analysis:
In-flight: Blood, feces.
Postflight: TBD.
 - D. Experiment Controls:
In-flight: None.
Ground-based: Matched littermates.
5. **SPACE STATION RESOURCE REQUIREMENTS:**
 - A. Special Equipment (other than common items): Automated animal vivarium; automated behavioral assessment.
 - B. Estimated Total In-flight Crew Time (hr/90 day, based on 1-g environment): 10 hr.
 - C. Experiment Site: LSRF: √ Attached Payload: poss Platform:

REPRODUCTION AND DEVELOPMENT HARDWARE USE AND CREW TIME (BY EXPERIMENT)

	TOTAL	EXPERIMENT CODE										
		R/D A	R/D B	R/D C	R/D D	R/D E	R/D F	R/D G	R/D H	R/D I	R/D J	R/D K
Crew time (hr/90 day)		20	5	5	0	6	5	5	15	TBD	0	0
Item												
Amphibian food	4											
Amphibian module	4											
Amphibian water	4											
Aquatic module	1											
Avian module	2									1	1	
Avian food	2									1	1	
Avian water	2									1	1	
Cage cleaner	22	1	1	1	1	1	1	1	1	1	1	
Cassette data recorder	1							1				
Development module	7	1	1	1	1			1				
Fish food	1											
Fish water	1											
Fixation kit	19	1		1		1	1		1	1		
Fluid handling kit	8					1				1		
Freezer (-20° C)	9	1				1	1		1	1		
Freezer (-70° C)	2											
G control centrifuge (8')	6								1	1		
G control centrifuge (small)	4											
Guillotine	13	1		1		1	1		1	1		
Hand wash facility	27	1	1	1	1	1	1	1	1	1	1	
Hematology analyzer	1											
Homogenizer	2											
Incubator	2									1		
Insect food	7											
Insect habitat module	7											
Insect water	7											
Mass measure, small	16	1	1	1		1	1		1			
Microscope, compound	1								1			
Microscope, dissecting	3						1					
Multi-purpose work bench	24	1	1	1		1	1		1	1		
Performance evaluation facility	1											
Radiation dosimeter (passive)	1											
Refrigerator (4° C)	12						1		1	1		
Rodent food	15	1	1	1	1	1	1	1	1			
Rodent module	15	1	1	1	1	1	1	1	1			
Rodent water	15	1	1	1	1	1	1	1	1			
Spectrophotometer	1											
Surgery/dissection kit	15			1		1	1		1	1		
Trash compactor	31	1	1	1	1	1	1	1	1	1	1	
Variable-G centrifuge (13')	3											
Video camera, recorder, supplies	13	1	1	1				1	1			

REPRODUCTION AND DEVELOPMENT HARDWARE USE AND CREW TIME (BY EXPERIMENT) (CONTINUED)

	EXPERIMENT CODE											
	R/D L	R/D M	R/D N	R/D O	R/D P	R/D Q	R/D R	R/D S	R/D T	R/D U	R/D V	R/D W
Crew time (hr/90 day)	20	30	30	5	1	2	2	10	8	30	2	8
Item												
Amphibian food		1	1	1						TBD		
Amphibian module		1	1	1						TBD		
Amphibian water		1	1	1						TBD		
Aquatic module									1			
Avian module										TBD		
Avian food										TBD		
Avian water										TBD		
Cage cleaner	1	1	1	1								
Cassette data recorder												
Development module												
Fish food									1			
Fish water									1			
Fixation kit	1	1	1						1	1	1	
Fluid handling kit		1	1	1				1				
Freezer (-20° C)									1	1		
Freezer (-70° C)												
G control centrifuge (8')	1											
G control centrifuge (small)		1	1	1						1		
Guillotine		1	1									
Hand wash facility	1	1	1	1		1		1	1	1	1	
Hematology analyzer												
Homogenizer								1			1	
Incubator	1											
Insect food					1	1	1	1			1	1
Insect habitat module					1	1	1	1			1	1
Insect water					1	1	1	1			1	1
Mass measure, small	1		1	1					1			
Microscope, compound												
Microscope, dissecting						1				1		
Multi-purpose work bench	1	1	1	1		1		1	1	1	1	
Performance evaluation facility												
Radiation dosimeter (passive)												
Refrigerator (4° C)	1	1	1						1		1	
Rodent food										TBD		
Rodent module										TBD		
Rodent water										TBD		
Spectrophotometer								1				
Surgery/dissection kit	1	1	1									
Trash compactor	1	1	1	1	1	1	1	1	1	1	1	1
Variable-G centrifuge (13')									1	1		
Video camera, recorder, supplies		1					1		1			1

REPRODUCTION AND DEVELOPMENT HARDWARE USE AND CREW TIME (BY EXPERIMENT) (CONCLUDED)

	EXPERIMENT CODE								
	R/D X	R/D Y	R/D Z	R/D AA	R/D BB	R/D CC	R/D DD	R/D EE	R/D FF
Crew time (hr/90 day)	8	5	5	2	10	19	15	90	10
Item									
Amphibian food							1		
Amphibian module							1		
Amphibian water							1		
Aquatic module									
Avian module									
Avian food									
Avian water									
Cage cleaner		1	1	1	1	1	1	1	1
Cassette data recorder									
Development module			1	1					
Fish food									
Fish water									
Fixation kit		1	1		1	1	1	1	1
Fluid handling kit		1							1
Freezer (-20° C)								1	1
Freezer (-70° C)					1	1			
G control centrifuge (8')		1				1		1	
G control centrifuge (small)									
Guillotine		1			1	1	1	1	
Hand wash facility		1	1	1	1	1	1	1	1
Hematology analyzer									1
Homogenizer									
Incubator									
Insect food	1								
Insect habitat module	1								
Insect water	1								
Mass measure, small		1	1			1	1	1	1
Microscope, compound									
Microscope, dissecting									
Multi-purpose work bench		1	1	1	1	1	1	1	1
Performance evaluation facility									1
Radiation dosimeter (passive)			1						
Refrigerator (4° C)		1	1	1			1		
Rodent food		1	1	1	1	1		1	1
Rodent module		1	1	1	1	1		1	1
Rodent water		1	1	1	1	1		1	1
Spectrophotometer									
Surgery/dissection kit		1	1		1	1	1	1	1
Trash compactor	1	1	1	1	1	1	1	1	1
Variable-G centrifuge (13')				1					
Video camera, recorder, supplies	1					1		1	1

APPENDICES

A. LIST OF WORKSHOP CONTRIBUTORS

1. Experiment Contributors During Workshop
2. Experiment Contributors Before and/or After Workshop
3. Attendees Providing Workshop Support

B. EXPERIMENT DISPOSITION LIST

C. RATIONALE FOR CONDUCTING LIFE SCIENCE EXPERIMENTS ON ATTACHED PAYLOADS AND FREE-FLYING PLATFORMS

1. Experiment Site Issues
2. Hardware Systems and International Issues

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Appendix B. EXPERIMENT DISPOSITION LIST

Some of the experiments are the same or similar, while others merely represent the same discipline.

MC DONNELL DOUGLAS EXPERIMENT NUMBER:*

CODE # IN THIS DOCUMENT

Bone Loss:

(A)BL1a	CH-D
(A)BL1b	CH-C ¹
(W)BL2	R/D-A, B
(W)BL3	R/D-A, E
(W)BL4	CH-F ²

Muscle Loss:

(A)ML1a	MS/F-E
(A)ML1b	MS/F-A
(W)ML2	MS/F-A

Cardiovascular:

(A)CV1	CS-A
(W)CV2	Deleted ^{3, 4}
(W)CV3	R/D-E

Fluids and Electrolytes:

(A)FE1a	E/FE-A
(A)FE1b	E/FE-A ⁵
(W)FE2	E/FE-A ⁶

Metabolism:

(A)MB1a	MR/TM-E
(A)MB1b	Deleted
(W)MB2	Deleted ⁷
(W)MB3	Deleted ⁸

*Space Station Life Sciences Research Facility Technology Assessment and Technology Development Plan, 1983.

¹Experiment CH-C is similar except Rhesus monkeys rather than squirrel monkeys are proposed.

²Experiment CH-F is somewhat similar using Rhesus monkeys.

³Restrained subjects not appropriate for space station.

⁴Science rationale weak.

⁵Same experiment using a small primate.

⁶Same experiment using an instrumented Rhesus monkey.

⁷Study of metabolic balance in mice.

⁸Study of metabolic balance readaptation to 1 g in mice.

MC DONNELL DOUGLAS
EXPERIMENT NUMBER:*

CODE # IN THIS DOCUMENT

(W)MB4
(W)MB5
(W)MB6
(W)MB7

Deleted
MR/TM-A
MR/TM-E
MR/TM-E

Vestibular Physiology

(A)VP1
(A)VP2a
(A)VP2b
(A)VP2c
(A)VP2d
(A)VP2e
(A)VP2f
(A)VP2g
(A)VP3

NS-A
NS-E
NS-I, J, K, L, M, N, O, P, Q, R
NS-G, H⁹
NS-G, H¹⁰
NS-G, H¹¹
NS-G, H¹²
NS-G, H¹³
NS-L, N

Reproduction and Development:

(A)RD1
(A)RD2a
(A)RD2b
(A)RD2c
(A)RD3
(A)RD4
(W)RD5
(W)RD6
(W)RD7
(W)RD8

R/D-EE
R/D-N, M
R/D-L
R/D-B, E
R/D-A, C
R/D-I, J
R/D-B, E
R/D-E
R/D-A, D, E, K
R/D-A, D, E, K

Radiation Biology

(A)RB1
(A)RB2

RA-A, F
RA-A, F

Plant Studies and CELSS:

(A)PC1
(A)PC2
(A)PC3
(A)PC4
(A)PC5
(W)PC6

PL-E
PL-F, N
PL-L
CL-A
CL-K
PL-L

⁹Same experiment using a Rhesus monkey.

¹⁰Same experiment using a cat.

¹¹Same experiment using a pigeon.

¹²Same experiment using a frog.

¹³Same experiment using a goldfish.

MC DONNELL DOUGLAS
EXPERIMENT NUMBER:*

CODE # IN THIS DOCUMENT

(W)PC7
(W)PC8
(W)PC9
(W)PC10
(W)PC11

PL-E
PL-C, CL-C
PL-H, J
PL-K
MR-CR-A

Note: The initial letter in parentheses indicates the derivation of the experiment – (A) for the Ames report, “Life Sciences Research and the Science and Application Space Platform”; or (W) for the 1982 Life Sciences Workshop.

Appendix C. RATIONALE FOR CONDUCTING LIFE SCIENCE EXPERIMENTS ON ATTACHED PAYLOADS AND FREE-FLYING PLATFORMS

1. Experiment Site Issues

The LSRF will provide all the advantages of a pressurized laboratory with potential crew support for experiment procedures. It has the potential disadvantages of including vibration and low-level gravity transients during docking, centrifuge rotations, and other maneuvers. Another potential disadvantage is that experiments will have to be compatible with general human habitability requirements.

Attached payloads provide an ideal environment for experiments that require minimal or no crew time, a simple environmental control system, good planetary observation, or direct exposure to the space environment. These experiments could be powered by the space station and have some control and monitoring instrumentation within the LSRF. Disadvantages include higher time requirements and less flexibility when direct crew support is needed either during suited extravehicular activity or teleoperation of a robotic system.

Free-flying platforms have the advantage of very low-level vibration and isolation from space station activities and environmental contamination. Platforms can be relocated as needed and placed in space station co-orbiting sites or in polar platforms for optimal planetary monitoring. Co-orbiting platforms could be serviced by the space station crew and polar-orbiting platforms returned to the station area for this task when needed if, as proposed, this is required on no less than 2-yr cycles.

2. Hardware Systems and International Issues

Satisfactory precedents for using attached payload and platforms for life science experiments exist. An earlier NASA proposal for an unmanned, orbiting, automated animal habitat called BESS was under serious consideration for development during the 1970s. The European Space Agency is heavily involved in the use of platforms for life science experiments based on its EURECA and COLUMBUS Programs. The Japanese Space Agency is also considering accommodating life science experiments on its "Exposed Facility" unpressurized work deck, which will be attached to its pressurized space station Japanese Experiment Module (JEM). These attached experiments will be accessible by means of a remote manipulator arm which can bring them inside the JEM through an airlock.

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Report Documentation Page

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7. Author(s) Editors: Catherine C. Johnson and Roger D. Arno Richard Mains*				8. Performing Organization Report No. A-87160	
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15. Supplementary Notes *Mains Associates, Berkeley, California Point of Contact: Catherine C. Johnson, Ames Research Center, MS 240-9, Moffett Field, CA 94035 (415) 694-5768 or FTS 464-5768					
16. Abstract <p>The Advanced Projects Office of the Life Science Division at Ames Research Center, as part of its planning for the implementation of Life Science Research aboard the space station, convened a workshop to develop hypothetical experiments to be used as a baseline for space station designers and equipment specifiers to ensure responsiveness to the users, the life science community. The workshop was held in October 1985, at San Juan Bautista, California. Sixty-five intra- and extramural scientists were asked to describe scientific rationales, science objectives, and give brief representative experiment descriptions compatible with expected space station accommodations, capabilities, and performance envelopes. Experiment descriptions include hypothesis, subject types, approach, equipment requirements, and space station support requirements. The 171 experiments are divided into 14 disciplines.</p>					
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